THE UNIVERSITY OF ALBERTA

# RELATIONSHIPS BETWEEN SLOPE AND ASPECT IN AN AREA OF HUMMOCKY MORAINE, SOUTH CENTRAL ALBERTA

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled "Relationships Between Slope and Aspect in an Area of Hummocky Moraine, South Central Alberta," submitted by David Hugh Spence in partial fulfilment of the requirement for the degree of Master of Science.

ABSTRACT

The basic purpose of this study is to test the hypothesis that slopes in a given area show significant variation with changes in microclimate, as reflected by aspect. Analysis of slope profiles in an area of hummocky moraine, near Rumsey in South Central Alberta, reveals that south and east facing slopes are steeper than north and west facing slopes, so differences of slope angle with aspect are apparent in the area.

To test the relationship between erosion susceptibility and aspect, analysis for significant differences between a number of variables with aspect is carried out. These variables are soil depth, soil infiltration rate, soil moisture content, soil strength, soil aggregate stability, carbon content, grain size distribution, and percentage bare ground. Significance tests show significant differences with aspect for all the variables except grain size and organic content.

Slope materials on south and, to some extent, east slopes (steeper slopes) are found to be more susceptible to surface erosion by wash. Previous slope studies suggest that with the conditions experienced in the field area, erosion through runoff will produce net slope lowering. In the apparent absence of other contemporary slope processes in this area, it is thought that the morphology of the area is relict.

A number of hypotheses are put forward in an attempt to explain the slope morphology. The most plausible hypothesis, to explain the slope forms, is that of preferred mass-wasting on particular aspects in the immediate post-glacial period. Exploratory tests of this hypothesis produce a negative result, but this is not conclusive.

The results of the study serve to indicate the slowness of surface erodibility, in the absence of channeled drainage.

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# CHAPTER I

# INTRODUCTION

## 1.1. Objectives

The main hypothesis to be tested in this thesis is that,

> 'Slopes in a given area show significant variation with changes in microclimate, as reflected by aspect.'

The aims by which it is hoped to test the hypothesis can be summarized as follows:

1. To determine if microclimate, as reflected by aspect, is primarily responsible for variation in slope profile, and to produce evidence either for, or against the hypothesis that microclimate is an effective parameter.

2. To attempt an explanation of slope development in a selected area from the point of view of the resistance of the slope materials, on different exposures, to erosion. This could be accomplished by an assessment of the erodibility of soils on slopes of different aspects.

3. To assess the degree to which post-glacial, subaerial processes have been effective in re-shaping glacial depositional forms in an area where the approximate date of deglaciation is known.

## 1.2. General Site Selection

An area of hummocky moraine was chosen as suitable for a study of the effectiveness of aspect on slope development for a number of reasons:

1. Emphasis in slope studies has been on the development of valley side

slopes and their response to erosional processes. Invariably such studies have shown the dominant factor to be the presence of active corrasion at the base of the slope. The most widely accepted view has been that slope processes are accelerated as a result of undercutting by the river or stream, and asymmetry of valley cross-profiles has been attributed to the presence of the stream at the base of the steeper valley slope (Strahler, 1950; Melton, 1960; Currey, 1964). The slopes chosen for study have no streams at their base, so the complicating factor of basal corrasion is absent. Debris transported downslope remains in the hollows. An area of hummocky moraine provides conditions where no major agent of removal is active at the slope base; a situation seldom studied by geomorphologists.

2. Variation in parent material and its relative resistance to weathering and erosion has presented further complicating factors to the study of slopes (Emery, 1947; Kennedy and Melton, 1972). The choice of a small area of moraine allows a tentative assumption that the parent material does not vary significantly. If variation does occur it should be revealed through mechanical analysis of the underlying till.

3. Melton emphasized the problems of past erosional processes making analysis of the slope morphology extremely complex. It may be simpler to indicate changes in erosional processes on a morainic area where the time period since deposition has been relatively short.

4. Research designs in slope analysis repeatedly involve analysis of east-west trending valleys (Kennedy and Melton, 1972), which allow direct comparison of opposing north and south facing slopes. In an area of mounds and intervening hollows slopes on all aspects are available for study.

Beaty (1956), in his study of landslides in relation to slope exposure stated:

> It is difficult of course to find topographic situations in which 'other things' are equal and exposure then is the only difference between slopes.

An area of well developed hummocky moraine provides a relatively unique situation for slope study as a number of the complicating factors are removed.

## 1.3. Site Description

Gravenor and Kupsch (1959), investigated an area of glacial deposition in the Stettler - Drumheller area of South Central Alberta. Morainic forms in the area were described (p.50) as:

> ... irregular in outline and showing no pronounced elongation. They consist of a nondescript jumble of knolls and mounds of glacial debris. The knolls do not align into ridges and no dominant trends are discernable. These areas have the characteristic knob and kettle topography.

Gravenor and Kupsch concluded that the morphology of the area was formed after ice stagnation, with subsequent down melting resulting in the deposition of an extensive area of ablation moraine. Substantial areas of Alberta were similarly affected, but this region shows one of the most spectacular effects of the ice stagnation process. The present day morphology consists of low undulating hills, or mounds of moraine, separated by numerous hollows which are usually occupied by small ponds (PLATES 1 and 2). A small area of hummocky moraine between Stettler and Drumheller was selected for study.

### 1.3.1. Definition of the Study Area

The moraine between Stettler and Drumheller is particularly extensive and the mounds and hollows are notably well developed. The area covers approximately 1000 square km and has an east-west extent of 32 km. Practical difficulties of scale and time available prevented selection of a representative sample for the complete moraine system. Twenty to twenty five mounds were therefore selected for a pilot study. From air photographs a tentative site was chosen, east of Rumsey near

Plate 1: Extensive hummocky moraine - Big Valley.

Plate 2: Hummocky moraine - east of Rumsey near Highway 56.

Highway 56 (112° 44'W; 51° 51'N) (FIG. 1-1). Criteria used in the choice of site were, accessibility, and the fact that road construction at this site had resulted in some deep road cuts through the moraine. Limits of the selected area were defined by the construction of a circle of radius equivalent to 0.3 km on the ground. The circle was centred on the road junction between the Rumsey Road and Highway 56. All mounds within the defined area were then susceptible to intensive study (FIG. 1-2).

### 1.3.2. Climate and Vegetation

Weather data were unavailable for the immediate area, but records at Three Hills, 32 km west gave some indication of the climate of this region. Mean annual precipitation 1931-1960 was 38.91 cm and the mean annual rainfall 29.94 cm of which 19.32 cm were recorded in June, July and August. Most stations recorded highest rainfall in June. Mean daily temperature for May, July and August was 13.9°C, though the absolute maximum annual temperature range was -48.3°C to 40°C. Potential evaporation has been recorded at 50.8 cm per year. Wind directions are extremely variable. According to Koppen's classification the climatic conditions fall into the cool dry steppe climate (BSK).

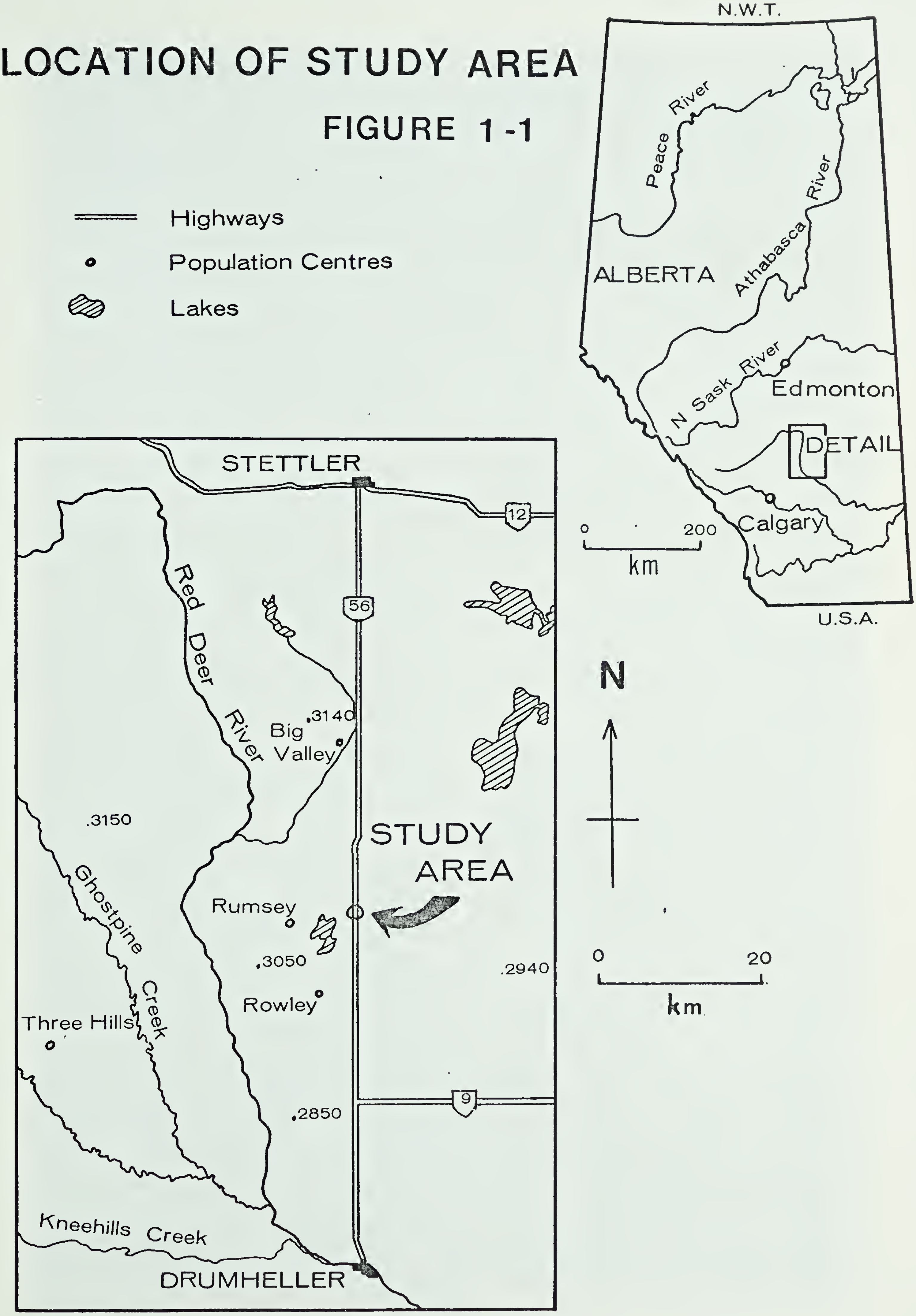
Vegetation consists of mainly grassland prairie species. Grass cover is dominantly blue gramma (*Bouteloua gracilis*) and spear grasses. The dominance of grassland prairie is not quite complete and some tree cover and scrub is in evidence in the hollows, especially on lower north facing slopes.

### 1.3.3. Soils

Classification of soils in the area by the Alberta Soil Survey shows that loam is the predominant soil type. They differentiate between the Hughenden Loam, and Halkirk Loam, on the basis of colour. A description of a Hughenden Loam is typical of the soil profiles encountered on the slopes of the mounds.

# LOCATION OF STUDY AREA

## FIGURE 1-1



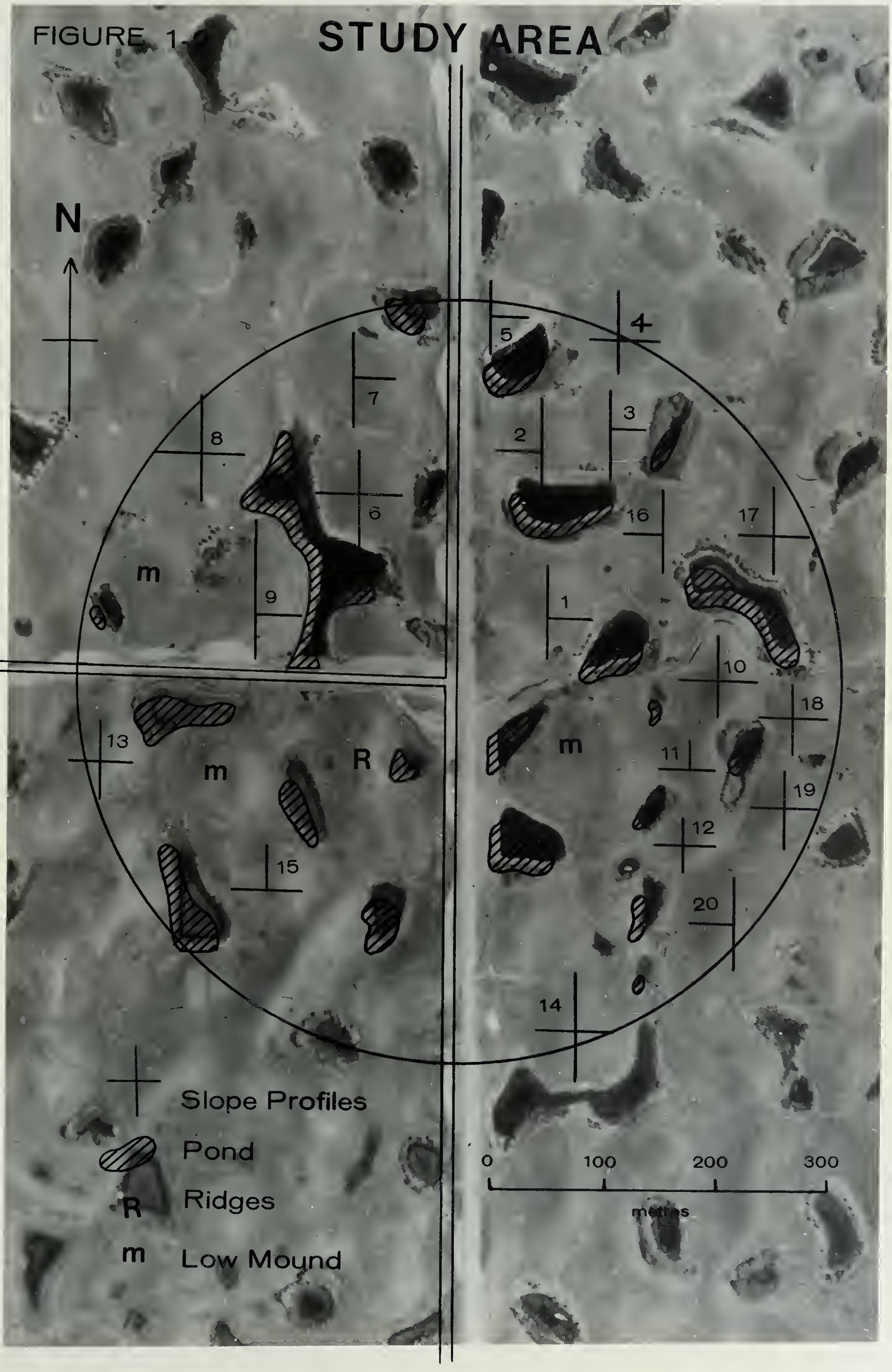


FIGURE 1-9
STUDY AREA
N
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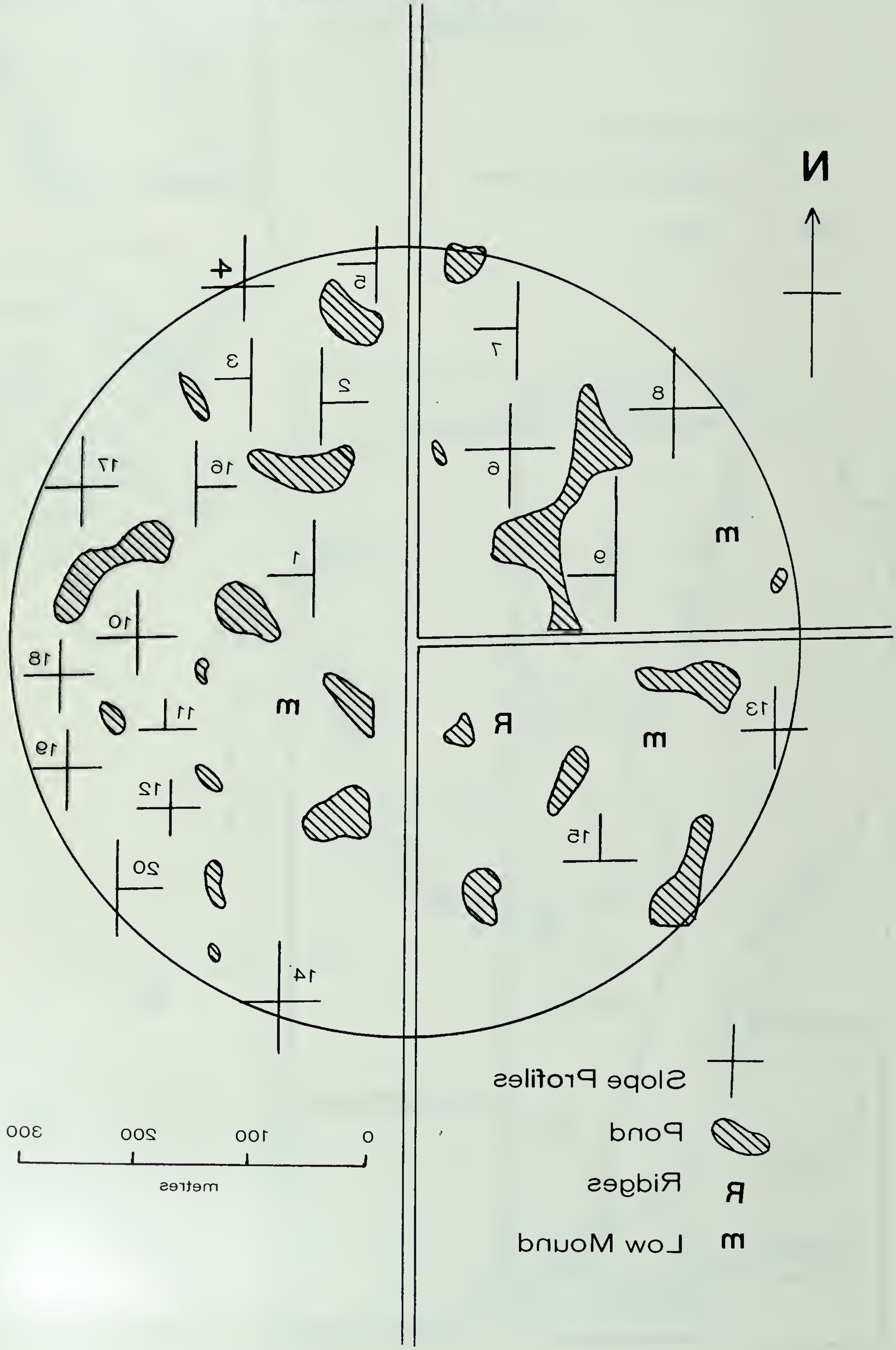
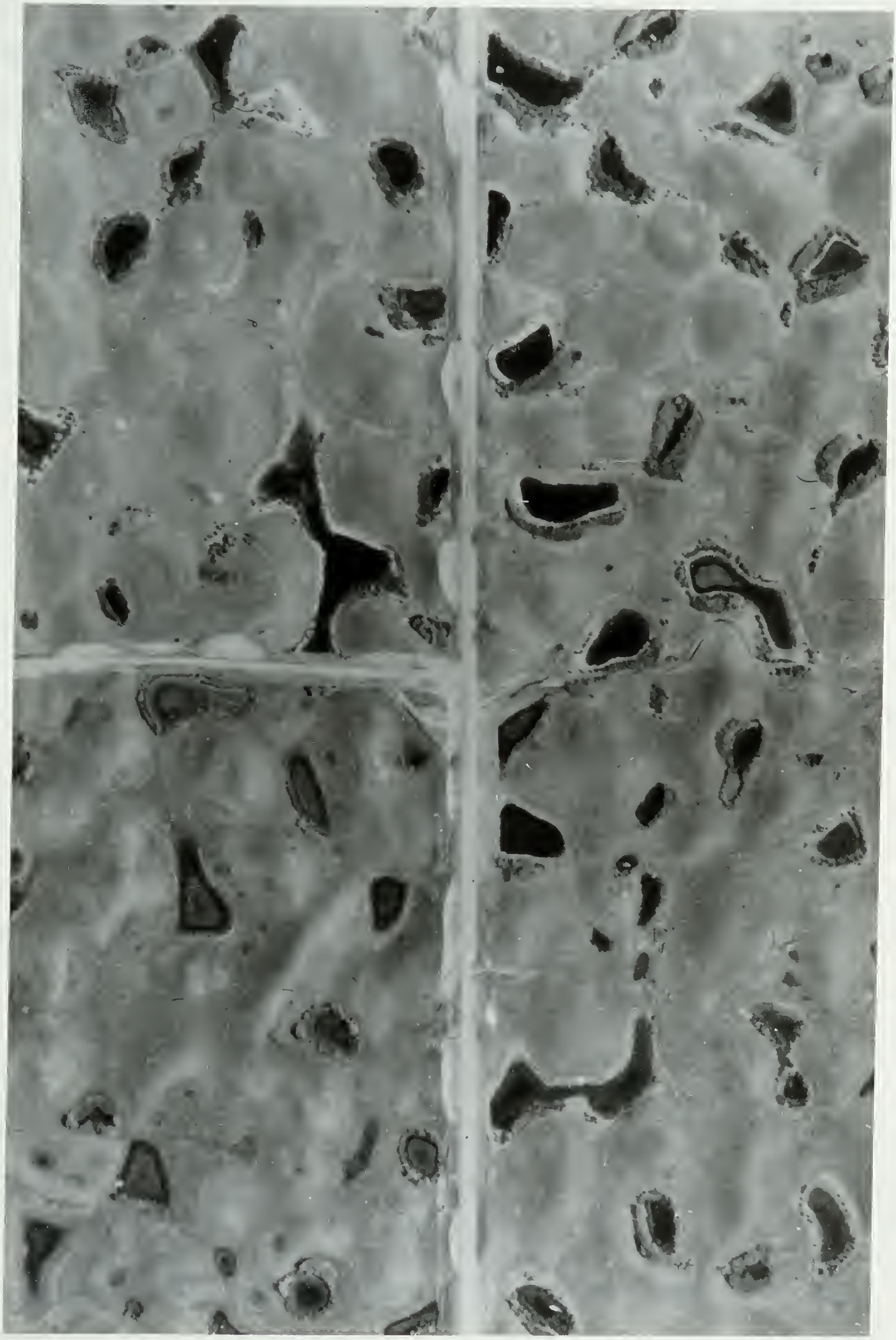
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
m
m
m
R
Slope Profiles
Pond
Ridges
Low Mound
0
100
200
300
metres

FIGURE 1-2

# STUDY AREA





HUGHENDEN LOAM

| CM | HORIZON | DESCRIPTION |
|---|---|---|
| 10 | A1 | Dark brown to very dark brown, prismatic. |
| 8 | $A_3$ | Brown to dark brown, prismatic. |
| 15 | $B_2$ | Strong brown, prismatic to columnar, friable, some staining on the cleavage surfaces. |
| 25 | $B_3$ | Brown, friable, some cleavage. |
| | $C_a$ | 50-60 cm from surface. |
| | C | Sandy clay loam. |

Horizons were not easily defined in the field, except for the very pronounced layer of calcium carbonate accumulation ($C_a$).

## 1.4. Approach and Methods

There are two possible approaches to a study of this nature:

(a) Direct approach

This approach involves a study of the rates of comtemporary slope forming processes on slopes of varying exposure (e. g. Schumm, 1956; Williams, 1957; Rudberg, 1958; Rapp, 1960). Erosional progress may then be related to precipitation and runoff (e. g. Stephens, 1968; Campbell, 1970). This approach was impracticable however, in view of the short period available for field study.

(b) Indirect Approach

Under the limitations of a short field program it appeared more profitable to observe reaction to slope processes mainly through a study of the soil response. Soil strength, soil depth, infiltration rates, variation in grain size distribution, and relative degrees of aggregation were selected as factors indicating the relative susceptibility of slope material to erosive processes. Reactions to slope processes, if any, should also be evident in the form of the slope geometry as revealed by the distribution of slope angles along a cross-profile.

Rudberg (1958), indicated the tendency for slope studies to be conducted in regions where slope processes are particularly active as for example in periglacial regions. The area to the north of Drumheller is a reasonably dry but well vegetated environment in which the activity of slope processes in the absence of rilling and gullying is presumably relatively slow. To the casual observer it appears that little denudation is taking place on the moraine. The presumed slowness of processes raised practical difficulties, but it was hoped that either an estimate of the degree of change in form of the mounds since deposition could be made, or that there may be some indication of a change through time of the dominant or controlling slope processes. The area presents a site with an environment of minimum variation. There are no major climatic differences or differences in types of vegetation such as usually encountered when field work is carried out over a large area. Any variation in soil type will be minimal as all soils come under the same soil classification.

# CHAPTER II

# THEORY

## 2.1. Slope Development with Aspect

Variation in steepness of slopes with different exposure, has long been accepted by geomorphologists. Such variations are thought to be prominent if there are very marked vegetational contrasts. The realisation that all river valleys were not symmetrical in cross profile led to various hypotheses to explain the asymmetry. Russell (1931, p. 484), proposed that preferential erosion took place due to snow accumulation.

> The relatively sunny southward slopes are barren for long periods during which northward slopes lie beneath thin sheets of snow. The snow protects the ground beneath from denudation during much of the critical winter period. Thus a contrast arises in the rate at which denudation takes place on the banks of any rills or streams flowing in directions approaching east to west. The northern bank being the more rapidly attacked, has its gradient lessened in comparison to the southern bank, hence arises the topographic contrasts observed.

Beaty (1956, p. 71) also testified to the importance of snow accumulation:

> Here and there is encountered the observation that north and east slopes are wettest because of snow accumulation, a fact obvious even to the most casual observer.

These ideas contrast with those of Von Engeln (1942). He observed that in arid areas north facing slopes were consistently more gentle than south facing slopes. Less evaporation and abundant vegetation on north facing slopes were the critical factors which he held responsible for the slope contrasts. This combination of factors he believed favoured the retention of weathering waste on the north facing slope.

Work completed by Walker (1948) in Wyoming on differential

erosion of north and south exposures, revealed the multiplicity of factors involved. Vegetational response to aspect was very apparent, with bunch grass on the south facing slopes, and forested north facing slopes. Southward running tributaries resulted in the deposition of alluvial fans causing deflection of the main channel and increased undercutting of the north facing bank. Walker also observed the presence of 'gophers', on the south facing slope, which were active in transporting quantities of fine material to the surface. This material could then be easily transported downslope. He concluded that vegetation distribution, a strong reflection of differences in aspect, was the controlling factor in slope development. The importance of vegetation is a recurring topic throughout the literature. Putnam and Sharp (1940) who worked in Southern California believed landslides occurred more frequently on south facing slopes due to lack of vegetation. Beaty (1956) found 70 per cent of landslides he studied occurred on slopes with a north and east aspect. Aspect then seems to play an important role as far as the incidence of slope failure is concerned. In contrast to the observations of Putnam and Sharp (1940), Beaty (1956 p. 73) noted little correlation between exposure and vegetation distribution on the slopes on which slides were observed. The slides occurred in areas less exposed to the sun, i.e. wetter slopes. Optimum conditions were more often reached on the north facing slope.

> Other things being equal, mass-movement in the form of landslides dependant on water content, ought to operate more often on these (north) exposures. A corollary of this line of reasoning is that weathering processes on relatively gentle hillsides might proceed more rapidly on less exposed slopes (i.e. north) under the given conditions, because bedrock would be more frequently exposed by removal of regolith, and more moisture would be available.

While under the conditions outlined by Beaty (1956) landslides may be prone to occur on north facing slopes, Emery (1947, p. 68) pointed out the importance of vegetation when other forms of slope processes are operative.

> Thus, it is probable that the smaller amount of vegetation on the south-facing slopes of

> east-west trending valleys must result in a higher rate of erosion through sheet wash, eventually causing the development of gentler slopes where exposure to the sun is greatest.

Much of the early work on variation of slopes due to exposure has been reviewed by Melton (1960). He demonstrated the conflicting views of different authors and reviewed theories they submitted for slope development. Most believed that in the northern hemisphere the north facing slopes tend to be steeper (Emery 1947; Kennedy 1972). The conflict of ideas arose when Von Engeln (1942) and Büdel (1953) claimed the opposite was the case. Quantitative work by Strahler (1950) did not resolve the dispute, and Packer (1969) added fuel to the fire by claiming that in a plot of all slopes in an area of dissected glacial deposits in Ontario, aspect was of no importance. Melton (1960) came to the conclusion that unless an asymmetric fill causing asymmetric basal corrasion was maintained, differences in vegetation would not produce differences in valley side slope angles. Thus, he believed that the proximity and erosional activity of the channel, if any, at the slope base was of greater importance to slope angle than gradation processes acting on the slope surface. According to Melton (p. 140) the river channel is all important in the development of asymmetric valley profiles:

> Asymmetry can exist even in the steep gradient valleys, but only if the base of one slope facet is corroded more strongly than that of the opposite slope ... Thus, valley asymmetry that is the result of a variety of different causes can be attributed to a single mechanism, asymmetric basal corrasion.

This attitude has been supported by Leopold and Langbein (1962). They suggested the steepness of slopes would vary inversely with distance from the stream. Smith (1949) also believed that asymmetry was a response to "one sided stream erosion when the ground was perennially frozen", and that solar exposure resulted in a minimum of resistance to stream erosion on one side of the valley. The relegation of the importance of climate was taken a step further by King (1957). He attributed modification of relief to the spacing of streams and especially to the character of the bedrock. He believed that climate was of little importance, beyond the extremes of the desert and glacial environments.

On the other hand localised microclimatic differences are held primarily responsible for lack of symmetry in valley profiles by other researchers. Freeze-thaw frequency, snow accumulation and prevailing winds, led Beaty (1956) to conclude that, "other things being equal slope exposure can be a most important control in landscape evolution." McConnell (1966) expressed similar opinion:

> The apparent effect of microclimate variation on steepness of slope is that valley sides receiving small and variable amounts of solar insolation tend to be comparatively steep primarily because such conditions render mechanical weathering processes inordinately dominant.

Work in a permafrost area of the Cariboo Hills by Kennedy (1972) showed that variation in the local erosional environment was extremely low in the presence of an undercutting stream. She concluded that stream activity in a permafrost area was of little importance in producing variation of slope development.

Attempts to isolate the controlling factor in slope development have led to conflicting results mainly because the areas chosen for study were extremely complex. Structure has also been an important variable in slope studies. Varying resistances of parent material can modify the relationship between slope angle and slope exposure Emery 1947; McConnell 1966, p. 718). Conversely Thornbury (1954) and Melton (1960) both maintained that the thicker vegetation on north facing slopes was a controlling factor in the production of steeper hillsides.

In some cases geomorphologists have selected areas for slope study where one or more of the complicating factors is absent. Research on slopes where no agent of removal was present at the base of the slope has been completed by Hoppe in Northern Sweden (1952); and Rudberg (1958) also in Sweden. Hoppe worked in an area of dead ice moraine consisting of irregular terrain with many small bogs and lakes, very similar to the topography of the chosen field area in South Central Alberta. The mounds were 10 to 15 metres high, and he found that slope inclinations of 25° to 30° were most common. He described accumulations of boulders in the

hollows between the mounds and indications on the slopes that these boulders had recently rolled to this position. He proposed that the moraine was modified both during and after the melting phase. This he believed was partly as a result of stream erosion, but principally due to mass-movement (solifluction, slips, falls, slides, etc.) This is understandable as the ice wall support was removed from sediments which were saturated and therefore extremely liable to flowage. Hoppe came to the same conclusion as Packer (1964), that there was no morphological difference between ridges of different exposures. Rudberg studied the degree of mass-wasting in a similar area by studying the orientation of pebbles in the surficial slope deposits. Lundqvist (1949), had demonstrated that elongated stones lie with the long axis parallel to the direction of movement of flowing debris. Rudberg measured the thickness of the layer in which orientation was evident, but could only say that sometimes it exceeded 0.5 m in depth and sometimes it was less. This could however be an effective method of studying the past slope processes. There is, therefore, considerable conflicting evidence that the consequence of slope aspect may have differing influences under different conditions. The area chosen for study is in essence a very simple situation where the conflicting factors, which in the past have led to conflicting results, are considerably reduced.

# CHAPTER III

## LABORATORY AND FIELD METHODS

### 3.1. Introduction

Possible variation in response to changes in microclimate on four aspects, north, south, east and west, was studied under a number of indirect measurable parameters.

1. Soil depth
2. Soil strength
3. Soil moisture
4. Soil infiltration rates
5. Aggregation of soil particles
6. Size distribution of soil particles
7. Percentage bare ground
8. Organic content
9. Relative mass-wasting
10. Measurement of slope form

In addition to the above, relative soil erodibility on soil samples taken from all four aspects was determined in the laboratory by rainfall simulation. The experiments were intended to check the dependence of erodibility on aspect. In some cases it was not possible to collect data on all the parameters for every slope. The tedious and time consuming nature of field infiltration studies, in particular, necessitated a reduction in the sample size for this parameter, and the number of mounds selected was therefore reduced by 50 per cent.

### 3.2. Soil Depth

Degree of horizon development and soil depth were studied by the use of soil pits. The indistinct nature of the transition zone between the B and C horizon necessitated the choice of another parameter to

represent soil depth. The distinctive feature of each of the soil profiles investigated was the presence of a very pronounced white layer of calcium carbonate at depth ($C_a$ layer referred to in the description of Hughenden loam). Leaching of carbonates in drift has been employed as a measure of variation in climatic environments and in dating tills of differing glacial periods (Thorpe, 1941; Flint, 1949). Leaching of carbonates is a process active under certain soil forming conditions in glacial drift, rich in carbonates. It is believed that with time the leached zone will increase in depth to a maximum dictated by rainfall amount, evaporation and soil structure. The calcium carbonate is then precipitated as a continuous layer. A major control is exerted by the parent material, but any variation in the till underlying the study slopes is expected to be extremely minor. Another problem in using depth of leaching is the effect of major climatic change, but the limited size of the study area means a change in climate would affect the whole area. Extreme caution must be used in the interpretation of results of depth of leaching measurement. Flint (1949) stated that "results of measurement of the leached zone yield values that are at best only relative." It would seem that at the sites chosen for study the number of variables affecting depth of leaching has been greatly reduced and the method may produce valuable results.

## 3.3. Soil Strength

The strength of a soil can be measured in the laboratory, but the basic problem in using such tests is that the sample has been removed from its natural environment, thereby reducing the natural stresses that the soil experiences. The best solution is to attempt to assess soil strength in the field. In order to obtain field measurement of soil strength two types of penetrometer were adopted:

A. Proving Ring Penetrometer

The instrument adopted is similar to that used by Chorley (1959) and Carson (1967). It consists of a conically pointed 18 inch penetration rod, which when forced into the soil can be used to measure the resistance to penetration on a proving ring, of 250 lb. capacity,

which is fixed on the handle (PLATE 3). Some measure of the compactness of the soil, and an indication of the soil shear strength is attained. The field procedure used was as follows:

1. Each site was prepared by removal of surface vegetation so that the surface of the soil was visible.
2. The Penetrometer was held normal to the slope of the soil surface, and after zeroing the gauge, pressure was exerted on the handle.
3. The gauge recording the maximum pressure required to drive the cone into the soil was read and recorded.
4. The process was repeated at least five times.
5. As resistance in the area was very high, conversion factors were used to obtain the actual penetration. (e.g. In the case of a cone entering only 50 per cent of the cone height the gauge reading was multiplied by 4. If only 25 per cent of the cone achieved penetration then the gauge reading was multiplied by 16.)
6. The proving ring calibration chart was used to determine maximum penetration load in lbs.

The proving ring penetrometer has been used to obtain reputable results, but there are problems of striking or grazing stones.

B. Pocket Penetrometer

The pocket penetrometer was employed to record variation in penetration resistance with depth in the soil pits. The resistance to penetration measured by the compression of a spring in the handle marks the resistance directly in tons per sq. ft. The instrument was used to record variation at 5 cm intervals from the surface to a depth of 40 cm. Extreme care was used in the interpretation of the results as this penetrometer is recognised as having only $\pm$ 20 per cent accuracy.

With results obtained in the field using these instruments it should be possible to indicate variations in soil shear strength in the region.

Plate 3: Proving Ring Penetrometer.

Plate 4: Concentric Ring Infiltration Apparatus.

## 3.4. Soil Moisture Content

Soil samples were sealed in polythene bags in the field and transferred to the laboratory. The moisture content was determined by application of the formula below to parameters determined by standard laboratory methods.

$$Wm = \frac{Ww - Wd}{Wd - Wc} \times 100 \text{ per cent}$$

Wc = Weight of container

Ww = Weight of container and wet soil

Wd = Weight of container and soil after drying overnight at 105° C.

Wm = per cent moisture content.

## 3.5. Soil Infiltration Rates

Laboratory methods of measurement of infiltration in soils (Slater and Byers, 1931) demonstrate the convenience of laboratory work. However, when sampling cylinders are used there is greater difficulty in obtaining an 'undisturbed soil sample', not to mention the effect of discounting the effects of the sub-soil on the infiltration rate. In view of the above limitations direct measurement in the field was adopted. The basic method involves the maintenance of a head of water on the soil surface and measurement of the amount of water needed to maintain this head against time.

Two field methods seemed applicable to the conditions in the study area.

A. Infiltration Tubes

Carson (1967) used a 1/8 inch thick graduated perspex cylinder 2 inches in diameter and 24 inches in length with the end twisted 2 inches into the soil surface. The tube was filled to a height of 22 inches and a constant head was maintained. His index of infiltration was the amount of water used in the course of a two hour test. This method had the advantage over the second method in that it was particularly suited to being used on slopes, as problems of variation in depth of head of water are eliminated.

B. Cylinder Infiltration

This apparatus was used by Lewis (1937), Parr and Bertrand (1960), Verma and Toogood (1968). Concentric cylinders are placed a few inches into the soil surface and a constant head of water maintained in the inner cylinder (PLATE 4). The outer cylinder is used as a buffer area surrounding the central compartment so that lateral absorption is minimised. The amount of water used at set time intervals is then representative of the infiltration rate.

Tests using both techniques in the field showed extremely variable results when the tube method was used. Carson (1967) also found that his results were extremely variable using this method. As the tube method necessitates removal of the surface vegetation, and insertion of the tube, considerable disturbance is caused to the small area of soil surface through which the water infiltrates. In fact the structure of the top two inches of soil and the surface soil conditions are effectively destroyed. Under these circumstances the concentric cylinder method was chosen, as results using this apparatus were reasonably consistent.

A double cylinder infiltration apparatus was obtained, as used by Verma (1968). The rings were 10 cm high made from 14 gauge galvanized iron sharpened at the lower edge. The inner ring diameter was 20 cm and the outer ring 30 cm. Field procedure was as follows:

1. Soil samples for analysis of moisture content were taken prior to each infiltration.
2. The concentric rings were driven 2-4 cm into the soil surface using a flat board.
3. The soil surface was not prepared as in some previous studies, no vegetation was removed, and as little disturbance as possible was made.
4. As some disturbance during placement of the rings is inevitable, the cylinders were left _in situ_ for one week to allow for some adjustment.
5. Water was introduced to both the inner and outer rings until at least 1 cm of head covered the inner area.

6. Graduated plastic tubes of one litre capacity were used to maintain a constant head of water in the inner ring, while the outer cylinder was periodically maintained at a reasonably constant depth.
7. The volume of water required to maintain a constant head of water in the inner cylinder was recorded at 1, 5, 10, 15, 20, 25, and 30 minutes, and thereafter every 15 minutes until two hours had passed after the initial head was established.
8. Records of the volume of water used at the set time intervals were then converted to give infiltration rates in cm per hour.

Infiltration curves were then plotted. The time when the curves level off, and show a fairly constant rate of infiltration, is a function of the pore geometry, breakdown of soil aggregates and the swelling of the clays. This measure indicates the susceptability of slopes to runoff, as runoff will occur when the infiltration rate of the soil is less than the rainfall intensity. A criticism of the method is that values obtained do not reflect the resistance of aggregates to the impact of raindrops, or to the sorting action of rainfall, both of which tend to seal the soil surface. A correction factor for turbidity has been developed by Free, Browning and Musgrave (1940), on the basis of experiments with rainfall simulators. The formula used was:

$$Y = 0.545\ X^{0.905}$$

Where: Y = Infiltration rate in turbid water.
X = Infiltration rate in clear water.

## 3.6. Aggregation of Soil Particles

The stability of the aggregates is a good indicator of the resistance of the soil surface to erosion especially when this data is combined with the data on infiltration and soil strength. Bryan (1969, p. 156) attributed high erodibility, with soils with clay contents of 17-20 per cent, to the lower water-stability of their aggregates. The clay content of surface soils in the study area is from 16-18 per cent, so it is accepted that higher percentage aggregation will increase the resistance of the soils to erosion.

The weight of aggregates was determined in the laboratory by a process of wet and dry sieving. The method chosen is based on Yoder (1936) as refined by Bryan (1968). The laboratory procedure was as follows:

1. Soil samples were obtained with as little disturbance to the soil structure as possible.
2. Samples were stored and air dried before the analysis was carried out.
3. Each sample was passed gently through a 8 mm sieve to remove stones.
4. 50 gm were separated and weighed for use in the analysis.
5. Each sample was dry sieved gently, by hand for one minute, through a nest of 4 sieves (sieve sizes 3 mm, 2 mm, 1 mm, 0.5 mm). The weight of aggregates retained on each sieve was then recorded.
6. The sieve fractions were recombined, flooded on a 3 mm sieve, and allowed to absorb moisture for 5 minutes, before being wet sieved through the above nest of sieves for a period of 20 minutes. The wet agitation apparatus used was developed by Bryan (1968) but is based on the principals introduced by Yoder (1936). It consisted of an electric motor and sieve holder such that the sieves could be fully immersed in water. The gentle vertical movement of the sieve was designed to reduce the mechanical abrasion of aggregates to a minimum and to prevent the aggregates being washed over the top sieve.
7. Water stable aggregates retained on each sieve were collected and dried overnight in an oven at 110°C.
8. Water stable aggregates were weighed and small stones > 2 mm were separated, weighed and subtracted from the total weight.
9. Distribution of dry and water stable aggregates were expressed as percentages of the original 50 gm sample, minus the weight of stones.

The major failing of this technique, as mentioned by Bryan (1968) is that aggregates which are water stable under conditions of gentle agitation in water may not be quite as stable under impact by high velocity raindrops encountered in the field. The method however is well suited to this type of study where a relative measure of aggregation is required.

## 3.7. Size Distribution of Soil Particles

Mechanical analyses of the samples were performed in three stages, preparation of the sample for analysis, separation and sieving of the sand size particles, and a sedimentation test of silt and clay fractions. The procedure followed was based on a standard sizing analysis procedure (Ackroyd, 1957).

(a) Pre-treatment

1. The sample was dry sieved through a 4 mm mesh to remove stones.
2. Any visible humus was removed by hand.
3. In order to remove organic matter 25 gm of soil were heated at 65°C in $H_2O_2$ until frothing ceased.
4. Disaggregation was achieved by the addition of 10 ml of 4.36 per cent sodium hexametaphosphate and sodium carbonate solution, and the mixture was allowed to stand overnight.
5. The solution was mixed for 10 minutes using an electric stirrer.

(b) Separation and Sieving of Sand Size Particles

6. Soil solution was wet sieved through a 0.063 mm sieve.
7. Sand size particles retained on the sieve were washed into an evaporating dish and oven dried at 105°C overnight.
8. The dried sand fraction was dry sieved through a nest of sieves, U.S. standard sieve sizes nos. 18, 35, 60, 120, 230, with mesh openings of 0.063, 0.125, 0.250, 0.5, 1.0 mm.
9. The amount retained on each sieve was weighed and recorded as a percentage of the weight of the pre-treated sample.

(c) Sedimentation of the Silt and Clay Percentages

10. Fines in suspension passing through the 0.063 mm sieve were poured into a sedimentation cylinder and the solution was brought up to 1000 ml by the addition of distilled water.
11. The cylinder and its contents were placed in a constant temperature water bath set at 25°C.
12. Before sedimentation was allowed to proceed the contents of the jars were agitated for a period of two minutes.

13. A 10 ml sample was taken by pipette at a depth of 10 cm at set time intervals of 4 min. 16 sec.; 1 hr. 8 min.; 7 hrs. 7 min.
14. 10 ml samples were oven dried at 105°C, cooled and weighed and the proportional percentages of the original pre-treated sample calculated.

### 3.8. Percentage Bare Ground

A simple measure of the vegetation cover was required. It was decided that an index of bare ground on each slope would suffice. A hundred foot tape was stretched out on each slope along the line of slope profile measurement and in the mid-section of the straight slope between the convex upper slope and concave lower slope. The number of inches of bare ground along the tape were then recorded and expressed as a percentage of the total tape length.

### 3.9. Organic Content

The method of dry combustion was adopted. Samples were oven dried at 110°C overnight to remove moisture and then weighed before placement in the furnace set at 450°C as suggested by Wilde and Voigt (1955) for 30 minutes or until a constant weight is reached. After cooling the samples were re-weighed and the loss of organic carbon calculated. This can be converted to organic content using the Van Bemmelen factor of 1.724, based on the assumption that soil organic matter contains 58 per cent carbon. However some dispute has arisen over the factor value. Allison (in Black 1965 p. 1368), suggested it was preferable to report organic carbon as such. The organic carbon therefore was calculated as the percentage weight loss of an oven dried sample after dry combustion in the furnace at 450°C for 30 minutes.

### 3.10. Relative Mass-Wasting

Slope materials can commence to flow under conditions of high soil moisture content. Mass-wasting may have been instrumental in the

formation of slopes in the study area by the processes of soil creep or solifluction. Two methods are used to investigate possible mass-wasting.

(a) Liquid Limit Test

Standard laboratory procedure as set down by Akroyd (1957) was adhered to. Samples for analysis were obtained at a depth of 60 to 100 cm from the soil surface. The procedure followed is given below:

1. An air dried soil sample was sieved through a no. 35 U.S. standard sieve.
2. The soil was thoroughly mixed with distilled water into a thick paste, and left for two hours.
3. The cup of the liquid limit device was half filled with the soil paste and levelled off, such that the maximum depth of soil was 1 cm.
4. A portion of the paste was set aside for analysis of moisture content.
5. The paste in the cup was separated, using the grooving tool, thus leaving a V-shaped gap.
6. The handle was turned at a rate of two rotations per second until the soil moved together in the groove over a length of 1.3 cm. The number of blows was then recorded.
7. The procedure was then repeated using the same soil until three recordings were made of the number of blows required.
8. The moisture content of the soil sample was then determined.
9. The process was then repeated four times for each soil, but at different moisture contents so that at least one of the average number of blows was greater or less than 25.
10. A graph of moisture content against the number of blows should approximate a straight line so that the moisture content at 25 blows can be ascertained as a measure of the liquid limit.

(b) Microfabric Analysis

'Undisturbed' soil samples were obtained by driving a tin can of small diameter into the soil profile at the required depths. The soil surrounding the can was then excavated and the downslope direction recorded before removal. In the laboratory the 'undisturbed' sample was removed from the can and the sample was impregnated with Scotchcast No. 3 impregnating resin. After hardening, the samples were cut and polished to produce thin sections suitable for examination by petrographic microscope. Using the direction of the long axis of those minerals exhibiting an axial ratio of at least 3:2, the orientation of at least 100 grains were recorded for each sample. Microfabric diagrams of the orientation of the minerals on the thin section were then prepared.

## 3.11. Measurement of Slope Form

Various techniques have been used in slope measurement, depending on the degree of accuracy required. Two methods seemed applicable to this study; the abney and tape method, and the inclined board technique. The first mentioned was used by Savigear (1956), Young (1963), Tinkler (1966), Carson and Petley (1970). It involves the placement of rods at the observed breaks of slope so that the operator can sight the rods with an abney level, and the distance between the rods can be measured with a linen tape.

Certain disadvantages of the method were instrumental in rejecting this type of approach. There is some possibility that breaks in slope might be overlooked, and generally an assistant is required. There are insufficient amounts, of data collected in this way on each profile for the construction of frequency distributions of slope angles.

In his "Scheme for Hillslope Analysis", Pitty (1969) found that the inclined board technique proved extremely useful in this type of analysis. He laid a three foot board on the surface and measured the inclination of the board with an abney level. The board was placed

along the total slope length so a large number of slope angles were recorded.

Advantages of the inclined board technique compared with other methods.

1. It is possible to obtain numerous data very quickly.
2. Results are useful for visual observation of the profile and sufficient measurements are produced for frequency distribution.
3. A separate distance measurement is not necessary as the operator is using a measured board, so the slope length can be calculated at a later date.
4. Only one operator is required.

Pitty's technique of data collection would seem to be most applicable to this study as it gives a high degree of accuracy and the required number of measurements.

## 3.12. Rainfall Simulation Tests

A direct test of soil erodibility was used in an attempt to confirm the results obtained by indirect methods described previously. A laboratory artifical rainfall simulator was made available for this kind of test. Soil samples on each slope were obtained from the surface 10-15 cm. The laboratory procedure adopted was similar to that used by Bryan (1968).

1. Samples were air-dried and passed through a 6 mm mesh.
2. The sample pan was prepared by inserting a layer of marbles in the pan and covering these with a layer of tissue. The prepared soil was then poured on top until the soil surface was level with the sides of the pan.
3. The samples were subjected to three minute periods of rainfall as described by Bryan. The first period was followed after sixty minutes by the second, and then after fifteen minutes the third period.
4. After each period the material washed-off the sample and material splashed-off the sample were collected in two buckets. Material on the splash screens was washed into the collecting buckets

using a wash bottle.

5. The quantity of soil solution is measured, and after agitation a sample of one litre was taken to assess the amount of soil in suspension. The remaining suspension was poured off and the soil residue washed into an evaporating dish to be dried over-night at 110°C.
6. The one litre sample in suspension was filtered using a vacuum pump, and filter paper and collected soil were dried overnight.
7. From the weight of soil residue, and soil suspension for the total volume of solution, the total soil loss can be calculated.

The intensity of the simulator, approximately 10 cm per hr., compares favourably with maximum rainfall intensities recorded in this region especially under conditions of severe thunderstorms (see table V-9 of monthly maximum rainfall intensities). The sequence of rainfall periods reproduce as much as possible situations which might arise under natural field conditions. The first thirty minute period corresponds to heavy rainfall on fairly dry soil which is more usual in this area. The second represents runoff when the soil is moist, and the third period represents possible loss through runoff when the initial soil is saturated.

CHAPTER IV

# ANALYSIS OF SLOPE MORPHOLOGY

## 4.1. Introduction

Within the defined field area all mounds exhibiting slopes on at least three orthogonals, north, south, east, or west, and with a vertical height greater than six metres are included in the analysis. Features rejected are:

1. Ridge features (e.g. S.W. quarter).
2. Low mounds less than 6 metres in height. (Three 'praire mounds' - low mounds with a rim and hollow in the centre similar to those studied by Bik (1969) - occur within the designated area).
3. Mounds where the morphology had been altered during the construction of Highway 56, and the Rumsey road.
4. Slopes on individual mounds where the straight portion of the slope profile between the upper convexity and lower concavity is less than ten metres in length.

After rejection the total sample of mounds within the defined area is twenty. Of these half show slopes on all four orthogonals, and half on three orthogonals. In total seventy slopes were surveyed.

## 4.2. Analysis of Slopes

Slope profiles were always measured along the orthogonal, though in some cases this did not necessarily coincide with the steepest slope. The slope data obtained is analysed in two ways:

a. Interpretation of the total profile data on each slope, from the summit of the mound to the low point in the hollow - Total Slope.
b. Analysis of only the straight section of each slope, between the convex upper slope and concave lower slope - Zone of

Maximum Declivity.

### 4.2.1. Total Slope Profile Analysis

Frequency tables of slope values on each mound are prepared, from which frequency profiles for each of the seventy slopes are drawn (selected examples FIG. 4-1). The class width is chosen as 2°. From the frequency profiles an analysis is made of:

1. Variation on each mound.
2. Variation on each aspect.
3. All slopes with regard to aspect.

From the frequency graphs median values for each slope are recorded. The range of median values is from 4° on the north slope of mound 8, to 16.5° on the south slope of mound 2. A table of median values (TABLE IV-1) indicates that, with few exceptions, north facing slopes record lower median values than the other three aspects. Exceptions are mounds 4 and 18 where west facing slopes show slightly lower values, and the south facing slope on mound 20. With the exceptions of mounds 12, 15, and 20, highest median values are found on south and east facing slopes. A plot of median values on each aspect (FIG. 4-2a) demonstrates the predominance of higher slope angles on south and east aspects. Median values are not very representative of the total slope so mean slope angle values are obtained using Folk and Ward's (1957) formula for skewed distributions:

$$M_z = \frac{\emptyset\,16 + \emptyset\,50 + \emptyset\,84}{3}$$

Where: $M_z$ = Mean value

$\emptyset$ 16, $\emptyset$ 50, $\emptyset$ 84 = Slope angle values at the 16th, 50th, and 84th percentiles.

The range of mean values is from 5° on the north of mound 17, to 13° 20' on the south slope of mound 2. South and east facing slopes in most cases show mean values greater than those of north and west facing slopes (FIG. 4-2b). Exceptions are mounds 12, 18, and 20. The range of means for north slopes is from 4° 20' to 10° 40' with an average of 6° 50', while the range of mean values for south facing slopes is from 8° 14' to 13° 20' with an average of 9° 56'. East slopes range from 6° 45'

# Slope Angle Frequency Distributions - Total Slope

FIGURE 4-1

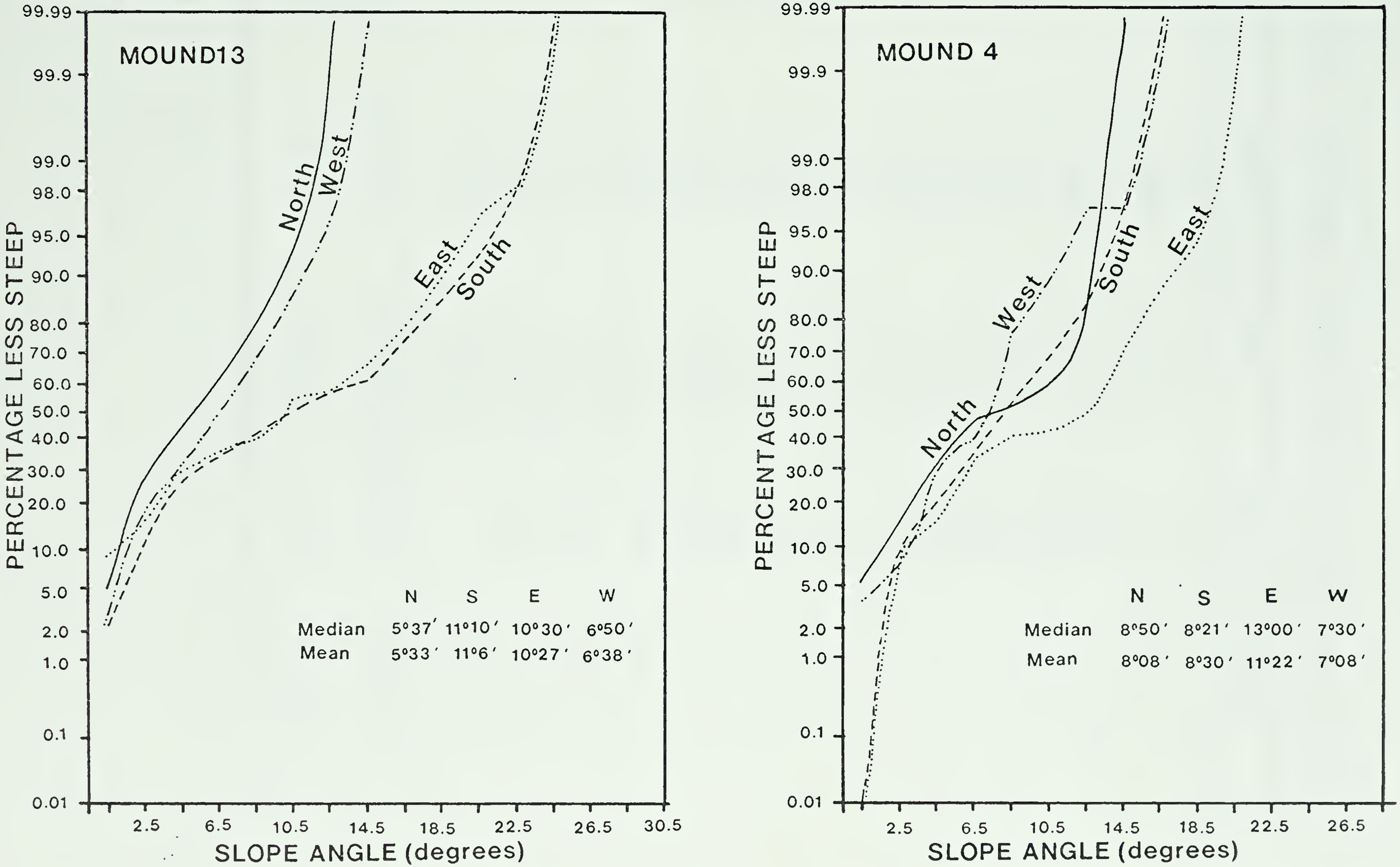


TABLE IV-1. TOTAL SLOPE - MEDIAN VALUES (in degrees and minutes).

| Mound | North | South | East | West |
|---|---|---|---|---|
| 1 | 9° 40' | 10° 40' | 13° 19' | - |
| 2 | 6° 40' | 16° 30' | - | 9° 54' |
| 3 | 6° 00' | 13° 10' | 10° 10' | - |
| 4 | 8° 50' | 8° 21' | 13° 00' | 7° 30' |
| 5 | 6° 10' | 13° 30' | 12° 30' | - |
| 6 | 5° 50' | 11° 50' | 10° 30' | 9° 30' |
| 7 | 7° 40' | 9° 26' | 10° 10' | - |
| 8 | 4° 00' | 8° 32' | 9° 54' | 8° 13' |
| 9 | 7° 21' | 15° 10' | 14° 10' | - |
| 10 | 7° 40' | 10° 30' | 12° 48' | 10° 30' |
| 11 | 5° 40' | - | 14° 50' | 9° 30' |
| 12 | 5° 40' | 8° 37' | 6° 30' | 9° 50' |
| 13 | 5° 37' | 11° 10' | 10° 30' | 6° 50' |
| 14 | 5° 06' | 8° 40' | 13° 30' | 8° 10' |
| 15 | 6° 00' | - | 10° 40' | 11° 37' |
| 16 | 7° 10' | 10° 00' | - | 10° 00' |
| 17 | 5° 10' | 8° 30' | 12° 50' | 8° 50' |
| 18 | 11° 19' | 12° 19' | 9° 50' | 7° 10' |
| 19 | 8° 20' | 9° 11' | 13° 42' | 9° 49' |
| 20 | 9° 50' | 8° 30' | - | 14° 19' |
| TOTAL | 139° 43' | 194° 36' | 198° 53' | 141° 42' |
| MEAN | 6° 59' | 10° 48' | 11° 41' | 9° 26' |

TABLE IV-2. TOTAL SLOPE - GRAPHIC MEAN VALUES (in degrees and minutes). Direction of skew indicated by positive or negative signs.

| Mound | North | South | East | West |
|---|---|---|---|---|
| 1 | 9° 30' - | 10° 30' - | 13° 07' - | - |
| 2 | 7° 33' + | 13° 20' - | - | 8° 39' - |
| 3 | 5° 27' - | 12° 08' - | 10° 00' - | - |
| 4 | 8° 08' - | 8° 30' + | 11° 22' - | 7° 08' - |
| 5 | 6° 50' + | 9° 21' - | 10° 37' - | - |
| 6 | 5° 53' + | 10° 11' - | 9° 41' - | 9° 11' - |
| 7 | 8° 07' + | 8° 27' - | 9° 08' - | - |
| 8 | 4° 20' + | 8° 16' - | 9° 43' - | 7° 55' - |
| 9 | 7° 26' + | 12° 41' - | 11° 59' - | - |
| 10 | 7° 09' - | 9° 57' - | 11° 14' - | 10° 30' 0 |
| 11 | 5° 55' + | - | 12° 12' - | 8° 39' - |
| 12 | 5° 10' - | 8° 14' - | 6° 45' + | 9° 03' - |
| 13 | 5° 33' - | 11° 06' - | 10° 27' - | 6° 38' - |
| 14 | 5° 07' + | 8° 23' - | 11° 28' - | 7° 38' - |
| 15 | 5° 51' - | - | 10° 29' - | 10° 10' - |
| 16 | 7° 09' - | 9° 30' - | - | 9° 03' - |
| 17 | 5° 00' - | 8° 43' + | 12° 18' - | 7° 40' - |
| 18 | 10° 40' - | 10° 37' - | 9° 49' - | 7° 07' - |
| 19 | 8° 39' + | 9° 27' + | 12° 17' - | 9° 01' - |
| 20 | 7° 59' - | 9° 32' + | - | 12° 40' - |
| TOTAL | 137° 26' | 178° 53' | 182° 36' | 131° 02' |
| MEAN | 6° 52' | 9° 56' | 10° 44' | 8° 44' |

FIGURE 4-2a **Median Slope Values and Aspect**

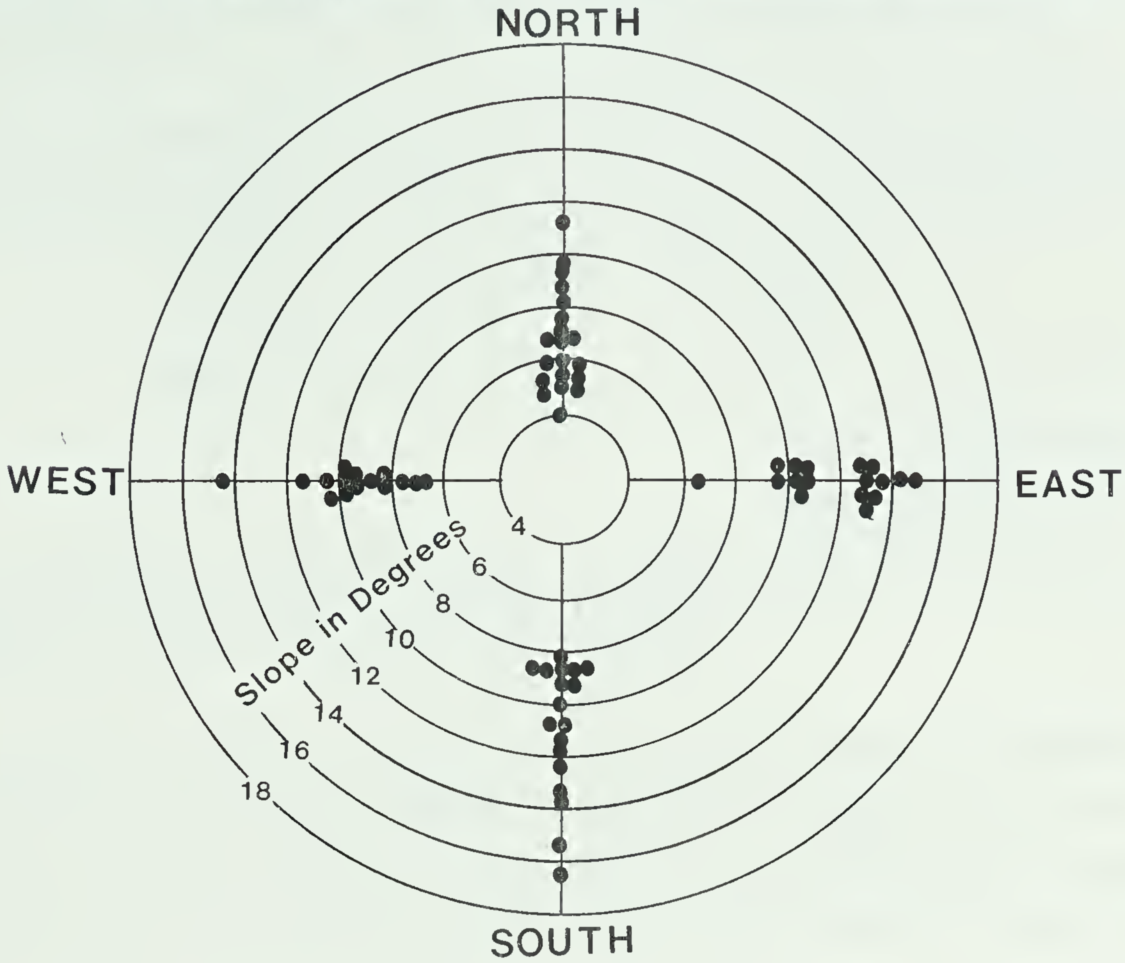
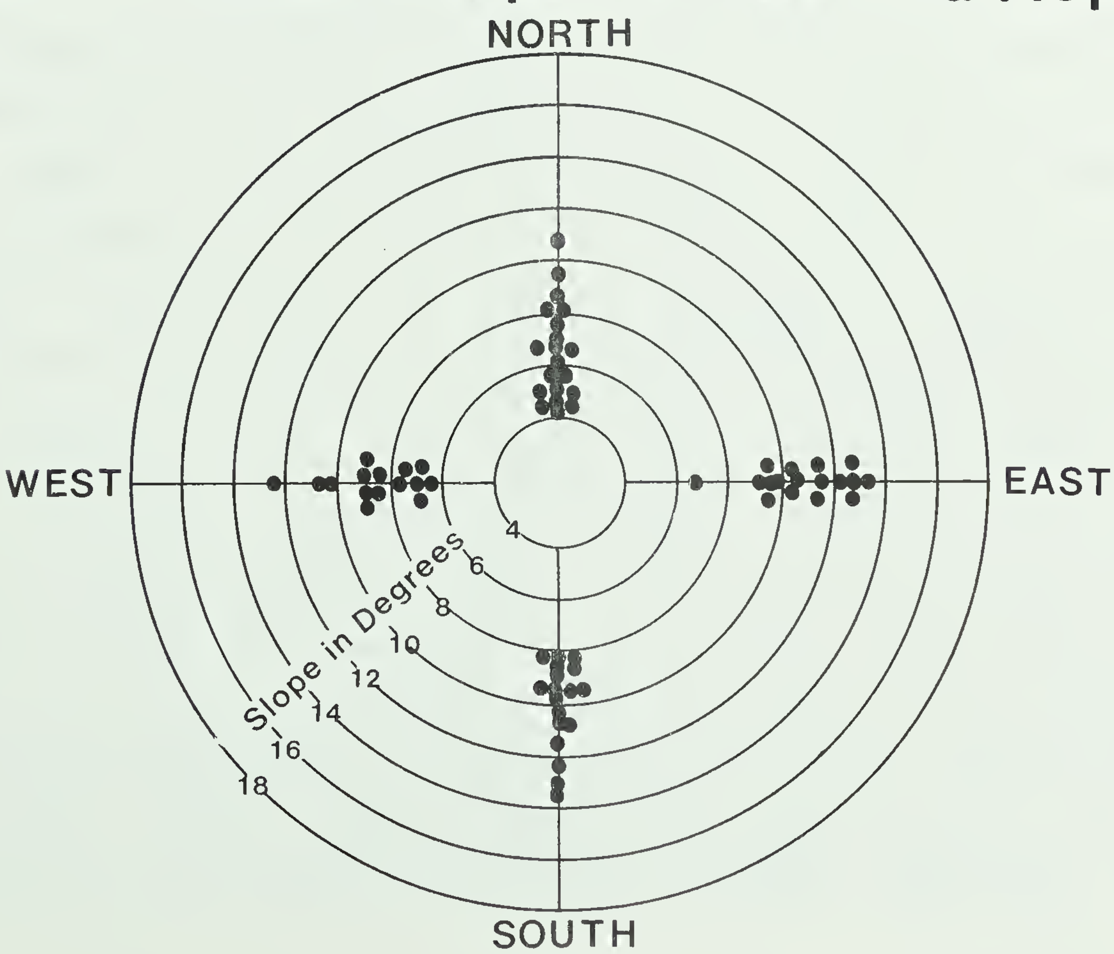



FIGURE 4-2b **Mean Slope Values and Aspect**



to 13° 07' for mean values, and the average is 10° 44', while west slopes range from 6° 38' to 12° 40' with an average of 8° 44'.

The distribution of angles on each slope profile is determined by applying the formula for standard deviation (Folk and Ward, 1957).

$$\text{St. Dev.} = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

Where: $\phi$ 5, $\phi$ 6, $\phi$ 84, $\phi$ 95 = Slope angle values at the 5th, 16th, 84th and 95th percentiles.

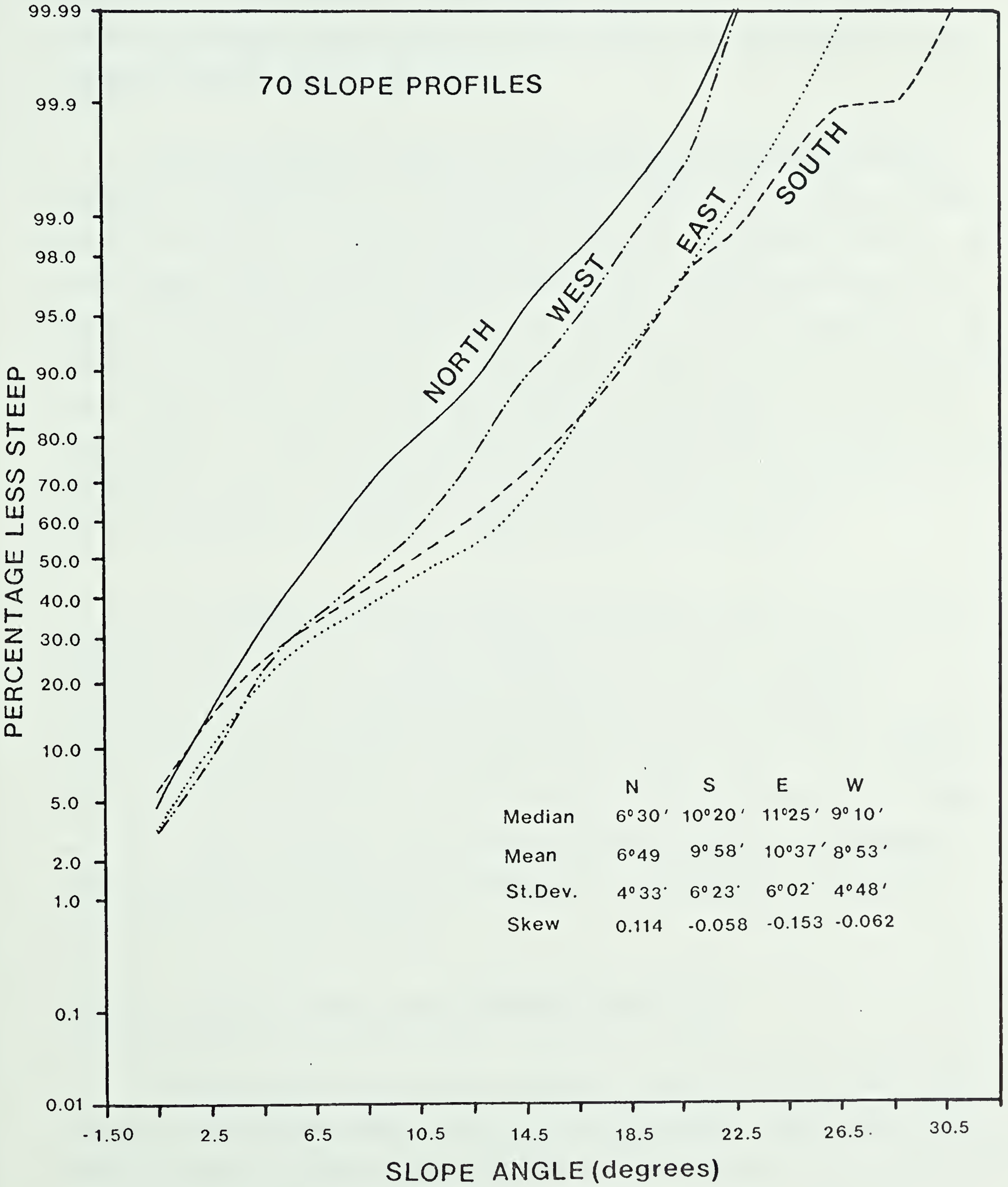
With one exception, mound 18 north, the variation about the mean value is greatest on south and east facing slopes.

Analysis of slope variation on each mound based on standard deviation mean, and median values, indicates a tendency for south and east facing slopes to bear a fairly close relationship, both aspects recording higher slope angle values than north and west facing slopes.

Data are amalgamated to produce frequency distribution graphs of slope angles for each aspect (FIG. 4-3). The distribution of lower angles on each aspect, show little variation. The significant departure in the distributions is with values greater than 6°. South and east distributions show an almost parallel distribution of higher slope angle values. The relative frequency of slopes less than 15° for example is, east slopes 72 per cent, south slopes 77 per cent, west slopes 91.5 per cent, and north slopes 97 per cent; or at 13°, east 56 per cent, south 65 per cent, west 80.5 per cent, and north 90.5 per cent. A positive skew occurs in the distribution of north facing slope angles. The other aspects demonstrate negative skewness and, therefore, a tail of lower values. East facing slopes record the highest average median and mean values of 11° 25' and 10° 37' respectively. Of the four aspects north slopes register the lowest average median and mean values of 6° 30' and 6° 49'. The measure of dispersion is higher for south and east facing slopes (i.e. steeper slopes), while north and west slopes show less variation. The position of the mode for each aspect is highly significant. The

FIGURE 4-3

# Mean Slope Angle Frequency Distribution
## Total Slope



mode for east slopes is 16° 30' while south slopes record a mode of 14° 30'. West and north slopes have modes of 12° 30' and 8° 30' respectively. (Modal values for individual mounds are not calculated as most show a bimodal distribution). The relationship already indicated in the analysis of individual mounds that south and east slopes are steeper than north and west slopes, is confirmed for the combined results from each aspect.

Initial tabulation shows the emergence of a definite pattern. Analysis of differences on each mound shows that two or three slopes out of the total of seventy do not conform to the general pattern. On each aspect south and east slopes demonstrate average means much in excess of the means for north and west slopes. In a comparison of the measure of central tendency on individual mounds the higher median and mean values are found, with few exceptions, on slopes with south and east aspects. Finally when observing the distribution of angles on all slopes with regard to aspect, the pre-set pattern of south and east slopes attaining consistently higher values is reaffirmed.

It is apparent that south and east facing slopes in the study area are the steepest. This statement is true for the majority of slopes in the area, but does not hold for all slopes studied. Inconsistencies are possibly explained by the fact that the complete slope profile was analysed. Consequently slopes may not be readily comparable as some slope profiles had extensive sections of low angle values. The low angle values tend to bias the data. To eliminate this bias slope analysis is confined to the straight or steepest section of the slope profile.

### 4.2.2. Analysis of the Zone of Maximum Declivity

Strahler (1950) has stated that the steepest part of the slope reflects the maximum angle that can be maintained. Consequently the zone of maximum declivity is probably the most sensitive to controlling conditions, and has been chosen for analysis. It was realised that

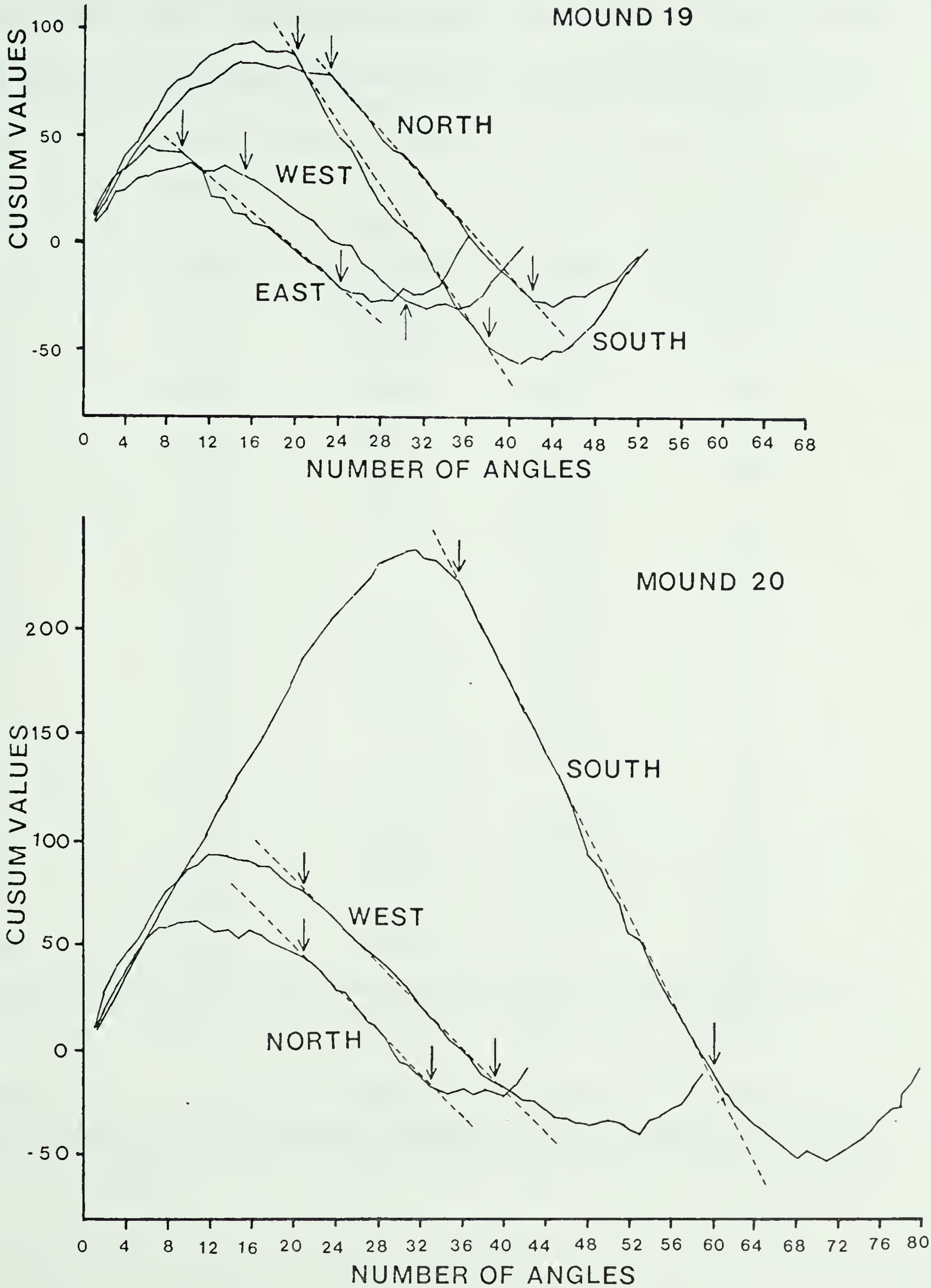
in an analysis of mound morphology an extensive summit section, or large hollow between the mounds, would result in a higher percentage of slope angle values in the lower categories, thereby influencing the analysis.

The problem in employing the zone of maximum declivity lies in defining the boundaries of this zone. In some circumstances breaks in slope are reasonably clear, but when dealing with concavo-convex slopes the problem becomes more complex. In the event of breaks of slope being difficult to define cusum charts are drawn as described by Pitty (1969). Cusum values are determined by taking the difference of each slope angle from the mean value for the slope, and cumulating the result. Small changes in slope values are thereby exaggerated graphically and it becomes easier to define the straight section of the slope by fitting a straight line to the graph (FIG. 4-4). Using cusum charts where necessary, a table of mean slope values for the zone of maximum declivity on each slope is compiled (TABLE IV-3). The mean slope values for each mound demonstrate a tendency for south and east slopes to have higher mean slope values. Diagrams of the frequency distributions (FIG. 4-5) of the mean slope values, best show the conspicuously higher values on south and east slopes. The pattern of slope angles related to aspect has been discussed qualitatively in section 4.2.1. However in order to establish a statistical significance for the results a valid quantitative test is required.

The four variables, north, south, east, and west are considered independent, so a statistical test for K independent variables applies. The data on each aspect is tested for normality and found to be highly skewed. A nonparametric statistic of analysis of variance is therefore chosen to avoid the assumptions of normality and homogeneity of variance associated with such parametric tests as the F-test. The Kruskal-Wallis one-way analysis of variance is adopted. Each of the seventy observations is ranked in a single series. The sums of the ranks for each variable are then analysed for disparity.

The two hypotheses tested are, Ho - there is no difference in the

FIGURE 4-4 **Cusum Charts**




↓ Limits of the zone of maximum declivity

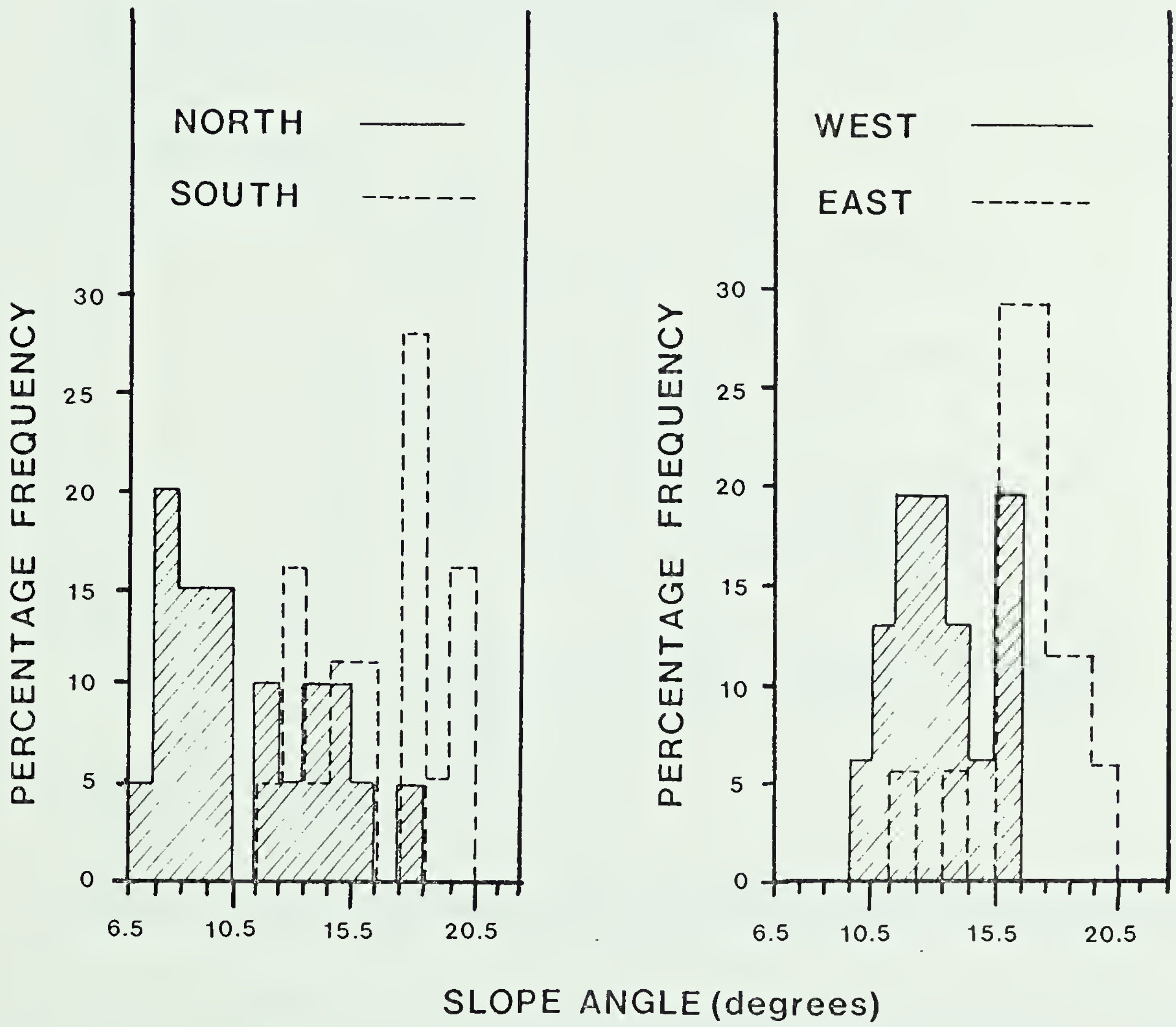
Cusum- Cumulative sum of variation from the mean slope angle

TABLE IV-3. ZONE OF MAXIMUM DECLIVITY - MEAN SLOPE VALUES (degrees).

| Mound | North | South | East | West |
|---|---|---|---|---|
| 1 | 14.72 | 17.71 | 19.90 | - |
| 2 | 11.71 | 19.71 | - | 11.90 |
| 3 | 8.34 | 17.60 | 15.93 | - |
| 4 | 12.66 | 12.74 | 16.08 | 10.31 |
| 5 | 12.48 | 19.64 | 15.81 | - |
| 6 | 9.98 | 15.82 | 15.70 | 14.41 |
| 7 | 14.02 | 13.12 | 14.22 | - |
| 8 | 8.33 | 13.48 | 16.17 | 13.22 |
| 9 | 9.25 | 18.33 | 17.08 | - |
| 10 | 10.41 | 17.50 | 16.67 | 16.33 |
| 11 | 10.25 | - | 17.87 | 12.94 |
| 12 | 7.45 | 13.98 | 12.49 | 12.20 |
| 13 | 9.09 | 18.91 | 18.72 | 10.97 |
| 14 | 8.74 | 12.02 | 17.41 | 12.17 |
| 15 | 8.44 | - | 18.47 | 15.95 |
| 16 | 13.60 | 15.21 | - | 14.83 |
| 17 | 8.10 | 15.16 | 18.96 | 12.66 |
| 18 | 17.87 | 16.25 | 16.72 | 11.14 |
| 19 | 14.89 | 17.93 | 17.34 | 13.78 |
| 20 | 15.50 | 19.98 | - | 16.39 |
| TOTAL | 225.83 | 295.09 | 285.53 | 199.20 |
| MEAN | 11.29 | 16.39 | 16.79 | 13.28 |

FIGURE 4-5

# Frequency Distributions for Mean Slope Angles - Slopes of Maximum Declivity



mean slope values of the zones of maximum declivity of north, south, east, or west facing slopes; and $H_1$ - that the mean slope values of the four variables are not equal. If Ho is confirmed then the H statistic is computed as chi square. The region of rejection of the hypothesis consists of all H values which are so large that the probability associated with their occurrence under Ho is equal to or less than 0.05. The formula used is according to Siegel (1956). Formula and computation are presented in table IV-4.

TABLE IV-4. ANALYSIS OF VARIANCE OF SLOPE ANGLE DISTRIBUTION WITH ASPECT.

Significance levels: 0.05 and 0.001

Formula:-

(Siegel, 1956)

$$H = \frac{12}{N(N+1)} \sum_{J=1}^{K} \frac{R^2_j}{N_j} - 3(N+1)$$

N = 70 (Total number of mean values)

K = number of samples

$N_j$ = number of cases in the jth sample

$R_j$ = sum of ranks to the jth sample

Computation:

$$H = \frac{12}{70(70+1)} \left[ \frac{(357)^2}{20} + \frac{(858)^2}{18} + \frac{(860.5)^2}{17} + \frac{(409.5)^2}{15} \right] - 3(70+1)$$

$$H = 32.8351$$

Degrees of freedom K - 1 = 3

Reference to the table of H values discloses the probability associated with the occurrence under Ho of a value of H of 32.83, df = 3 is 0.001. If the observed value of H i.e. 32.83 is equal or larger than the value of chi square then Ho is rejected at that level. Ho may then be rejected in favour of $H_1$ as the value of H from the tables was 16.27. It is concluded that mean slope values for the sample of seventy slopes vary significantly with aspect.

Having determined that differences are significant aspects are paired and slope values analysed to determine the direction of the differences. A number of null hypotheses are tested.

1. Mean slopes of north and south facing slopes are equal.
2. Mean slopes of north and west facing slopes are equal.
3. Mean slopes of south and east facing slopes are equal.
4. Mean slopes of west and east facing slopes are equal.

As with the analysis of variance the assumptions of the t-test are not met. The Mann-Whitney U test, a nonparametric statistic suitable for testing small samples, is used to determine the significance of differences between the values for the different aspect combinations. Values of each set of variables are ranked in one series and $R_1$ and $R_2$ (the sum of the ranks for each variable) calculated. Significance levels are set at 0.05 and 0.001 and a value for U computed from the formula: (Siegel 1956).

$$U = n_1 n_2 + \frac{n_1 (n_1 + 1)}{2} - R_1$$

Where: $n_1$ = the number of cases in the smaller group

$n_2$ = the number of cases in the larger group

$R_1$ = the sum of the ranks assigned to the group whose sample size is $n_1$

The same formula can be used to compute a value of U for $R_2$. Only the smaller of the two values of U is used. If the observed value of U is less than the value of U taken from tables of U values, at the set level of significance, then Ho is rejected at the level of significance. The results of the analysis presented in table IV-5 led to the following conclusions. South slopes are significantly steeper than north slopes at the 0.001 level. East slopes are steeper than west slopes at the same high level of significance. South and east slopes show no significance variation at the 0.05 level, while west slopes are found to be steeper than north slopes at the 0.05 level, but not at the 0.001 level.

TABLE IV-5. RESULTS OF MANN-WHITNEY U TESTS FOR DIFFERENCES IN MEAN SLOPE ANGLE WITH ASPECT.

| Hypotheses | $N_1$ | $N_2$ | U Table | Significance Level | Observed U Value | Conclusion |
|---|---|---|---|---|---|---|
| Ho N = S | | | | | | |
| $H_1$ S > N | 18 | 20 | 76 | 0.001 | 40 | Reject Ho |
| Ho N = W | | | | | | |
| $H_1$ W > N | 15 | 20 | 59 | 0.001 | 85.5 | Accept Ho |
| | | | 100 | 0.05 | | Reject Ho |
| Ho S = E | | | | | | |
| $H_1$ S > E | 17 | 18 | 61 | 0.001 | 145 | Accept Ho |
| | | | 102 | 0.05 | | Accept Ho |
| Ho E = W | | | | | | |
| $H_1$ E > W | 15 | 17 | 47 | 0.001 | 27 | Reject Ho |

Two approaches have been used to analyse variation of slope with aspect. Observation of frequency distribution of the total slope values reveals a tendency for north and to some extent west slopes to have lower slope angle values. Statistical measures help reveal this trend. Inconsistencies in length of slopes especially where profiles had extensive sections of low angle values led to a shift in the main statistical emphasis to an examination of the zone of maximum declivity. The analysis confirms the tendency revealed in the analysis of total slope, that south and east facing slopes are significantly steeper than north and west slopes, a result which is contrary to much of the theory of slope development and contradicts the work of Packer (1969) in similar glacial topography.

# CHAPTER V

## FIELD AND LABORATORY RESULTS

### 5.1. Soil Depth

Depth to the layer of accumulation of caliche was generally easily determined by visual observation. To validate observations of the depth of caliche hydrochloric acid was applied to the soil profile and depth to effervescence was recorded as the depth of the leached layer of soil. Table V-2 records the measurement of the depth of soil development. The values show a wide range from 5.5 cm, on mound 18 east, to 65 cm on mound 19 west. On each aspect mean values of depth of leaching for north, south and west facing slopes are very similar being 37.2, 35.4, 33.3 cm respectively. The only significant departure is the mean value of 20.3 cm recorded on east aspects.

The Mann-Whitney U test is utilized in a statistical analysis of the variation in soil depth. The results of the tests are summarized in Table V-1.

TABLE V-1. RESULTS OF MANN-WHITNEY U TESTS FOR DIFFERENCES IN SOIL DEPTH WITH ASPECT.

| Hypotheses | $N_1$ | $N_2$ | U Table | Significance Level | Observed U Value | Conclusion |
|---|---|---|---|---|---|---|
| Ho N = S | | | | | | |
| $H_1$ N > S | 18 | 20 | 76 | 0.001 | 98 | Accept Ho |
| | | | 123 | 0.05 | | Reject Ho |
| Ho N = W | | | | | | |
| $H_1$ N > W | 15 | 20 | 59 | 0.001 | 121 | Accept Ho |
| | | | 100 | 0.05 | | Accept Ho |
| Ho S = E | | | | | | |
| $H_1$ S > E | 17 | 18 | 61 | 0.001 | 10.5 | Reject Ho |
| Ho W = E | | | | | | |
| $H_1$ W > E | 15 | 17 | 47 | 0.001 | 34.5 | Reject Ho |

TABLE V-2. SOIL DEPTH - REFLECTED BY DEPTH OF CALCAREOUS LAYER (in cm).

| Mound | North | South | East | West |
|---|---|---|---|---|
| 1 | 44.0 | 21.0 | 23.0 | - |
| 2 | 38.0 | 25.0 | - | 45.0 |
| 3 | 23.0 | 18.0 | 15.0 | - |
| 4 | 47.0 | 38.0 | 30.0 | 28.0 |
| 5 | 20.0 | 41.5 | 18.0 | - |
| 6 | 26.0 | 44.0 | 28.0 | 24.0 |
| 7 | 64.0 | 38.0 | 17.0 | - |
| 8 | 37.0 | 33.0 | 20.0 | 22.0 |
| 9 | 23.0 | 42.0 | 16.0 | - |
| 10 | 16.0 | 30.0 | 21.0 | 35.0 |
| 11 | 34.0 | - | 31.0 | 18.0 |
| 12 | 41.0 | 32.0 | 23.0 | 30.0 |
| 13 | 39.0 | 40.0 | 14.0 | 24.0 |
| 14 | 58.0 | 24.5 | 24.0 | 33.0 |
| 15 | 33.0 | - | 11.5 | 33.0 |
| 16 | 50.0 | 40.5 | - | 31.5 |
| 17 | 20.5 | 40.5 | 23.0 | 40.5 |
| 18 | 33.0 | 40.5 | 5.5 | 30.5 |
| 19 | 47.0 | 44.0 | 25.5 | 65.0 |
| 20 | 52.0 | 45.0 | - | 41.5 |
| MEAN | 37.2 | 35.4 | 20.3 | 33.4 |

Significant differences at the 0.001 level are found between south and east sites, and east and west sites; east sites had shallower depths of soil. North and south facing slopes show significantly different values of soil depth at the 0.05 level.

The problem of interpretation of these results is complex as the depth of soil, as reflected by depth of the leached layer, could reflect either:

a. The solution of calcium carbonate by downward percolation and its deposition at depth, or

b. The degree of removal of the A horizon by contemporary slope processes i.e. the soil profile is truncated.

c. The possibility that the material on each aspect has had different carbonate content since the original deposition.

An explanation of the results in terms of the factors involved is not possible, but some qualitative assessment can be made. To some extent the low values on east and south facing slopes can be explained by progressive erosion of the A horizon. Observations of active surface soil movement were only recorded on mounds 3, 13, 15, and 18. All four mounds exhibited steep slopes and all were sparsely vegetated. Evidently, the conditions mentioned above may produce similar results for soil depth causing difficulty in any attempt to isolate a specific process response mechanism. Soil depth may therefore prove to be of doubtful use.

## 5.2. Soil Strength

### 5.2.1. Introduction

Soil strength was determined by estimating the relative shearing resistance by means of a ring penetrometer. Variations in shearing resistance may reflect dissimilarities in granulation and porosity. The force required to penetrate a standard cone is taken as a measure of the shearing resistance. Most authors emphasise the importance of soil moisture, which has a negative correlation with shearing resistance, when soil strength is determined by use of a penetrometer (Baver 1956, Shaw *et al* 1942). The negative correlation occurs especially with soils of a high clay content. Chorley (1959) points out that the

negative correlation does not necessarily apply with a granular soil which is much more sensitive to differences of soil density. He isolated four major factors controlling resistance to penetration. They are grain size and moisture content, both of which were in an inverse relationship, and range of grain size and soil density which were in direct relationship.

### 5.2.2. Results of Proving Ring Penetrometer Tests

Five readings of maximum pressure in pounds required to push the cone into the soil surface were taken at the mid-slope on each site. In all cases maximum penetration to only a few cm from the surface was achieved so penetration to the top of the cone was used as the standard measure of resistance. In some cases full cone penetration proved impossible and appropriate factors were used to convert the data. The mean results at each site are tabulated in Table V-3. The lowest load recorded is 117 lb. on mound 16 north, and highest of more than 250 lb. (the limit of the instrument) is recorded on mound 1 south. South and east facing slopes usually record high resistance to penetration. Anomalies do occur, notably mound 13 east where resistance is only 135 lb, lower than the resistance on the south slope of the same mound. In this case the anomaly could be explained by the fact that observation of the slope surface on mound 13 east indicated that the soil is actively experiencing downslope movement.

Tests for significant differences of soil strength between aspects, using the results of ring penetration, reveal that resistance on south slopes is significantly greater than that of north slopes at the 0.001 level; and significantly greater than east slopes at the 0.05 level (TABLE V-4). Greater resistance on west facing slopes as opposed to those facing north may be accepted at the 0.05 level of significance, but not at the 0.001 level. East slopes record greater resistance than west slopes at the 0.05 level. Soil strength on different aspects can be expressed in the decreasing series south > east > west > north. Slope failure would be more probable on slopes of north and west aspects than on south and east facing slopes. However, the possibility of slope

TABLE V-3. SOIL STRENGTH - BY RING PENETRATION (load in lbs.)

| Mound | North | South | East | West |
|---|---|---|---|---|
| 1 | 159 | + 250 | 136 | - |
| 2 | 155 | 245 | - | 203 |
| 3 | 168 | 184 | 175 | - |
| 4 | 163 | 193 | 202 | 168 |
| 5 | 124 | 182 | 191 | - |
| 6 | 122 | 189 | 210 | 166 |
| 7 | 158 | 212 | 165 | - |
| 8 | 131 | 205 | 156 | 146 |
| 9 | 140 | 172 | 212 | - |
| 10 | 148 | 196 | 174 | 167 |
| 11 | 128 | - | 189 | 152 |
| 12 | 169 | 192 | 190 | 171 |
| 13 | 144 | 168 | 135 | 132 |
| 14 | 138 | 187 | 174 | 172 |
| 15 | 150 | - | 202 | 157 |
| 16 | 117 | 178 | - | 141 |
| 17 | 137 | 204 | 163 | 158 |
| 18 | 146 | 182 | 186 | 139 |
| 19 | 153 | 218 | 183 | 157 |
| 20 | 154 | 208 | - | 145 |
| MEAN | 145.2 | 198.05 | 179.0 | 158.26 |

TABLE V-4. RESULTS OF MANN-WHITNEY U TESTS FOR DIFFERENCES IN SOIL STRENGTH WITH ASPECT.

| Hypotheses | $N_1$ | $N_2$ | U Table | Significance Level | Observed U Value | Conclusion |
|---|---|---|---|---|---|---|
| Ho N = S | | | | | | |
| $H_1$ S > N | 18 | 20 | 76 | 0.001 | 1.5 | Reject Ho |
| Ho N = W | | | | | | |
| $H_1$ W > N | 15 | 20 | 59 | 0.001 | 89.5 | Accept Ho |
| | | | 100 | 0.05 | | Reject Ho |
| Ho S = E | | | | | | |
| $H_1$ S > E | 17 | 18 | 61 | 0.001 | 91 | Accept Ho |
| | | | 102 | 0.05 | | Reject Ho |
| Ho E = W | | | | | | |
| $H_1$ E > W | 15 | 17 | 47 | 0.001 | 59 | Accept Ho |
| | | | 83 | 0.05 | | Reject Ho |

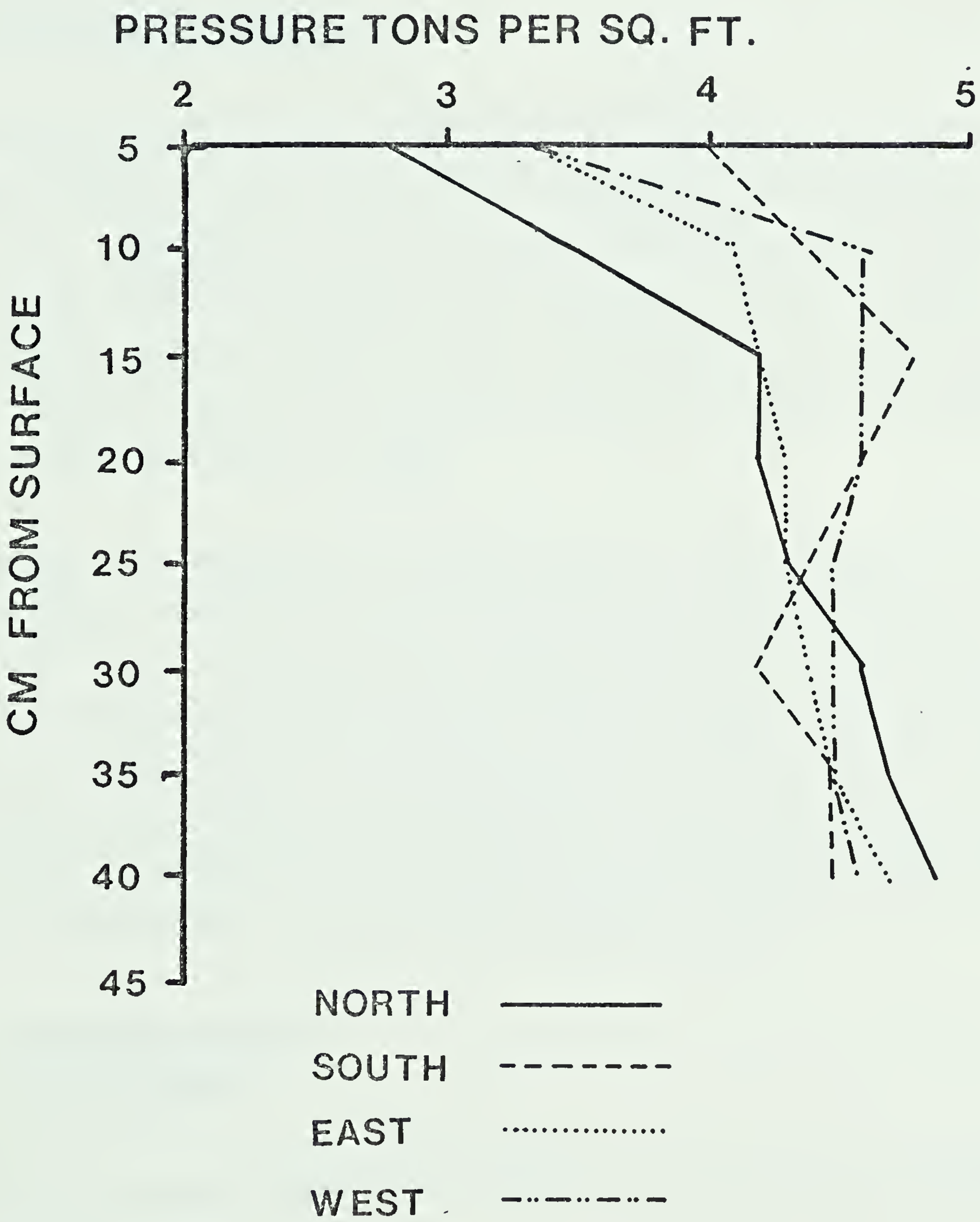
failure in this area is very slight and no indication of major past or imminent failure was observed. Alternatively the higher resistance to penetration may reflect greater compactness of soil on south and east aspects. Compactness aids wash erosion, as runoff is increased with a decrease of infiltration. The data collected does point to the very distinct differences which can be found in the physical make up of soil surfaces of different aspects.

### 5.2.3. Results Pocket Penetrometer Tests

Despite its limitations, the pocket penetrometer was used to determine variation in resistance with depth. Readings were taken at 5 cm intervals to a depth of 40 cm on the soil profile in the mid-slope position. Within 5 to 10 cm from the surface results are similar to those taken on the surface with the proving ring penetrometer. North slopes show least resistance and south slopes most resistance. Resistance to penetration on east and west slopes are almost equal. Figure 5-1 shows the mean penetration at depth on four aspects. A rapid increase in resistance with increasing depth to 15 cm from the surface is evident, and between 15 and 25 cm north

FIGURE 5-1

## MEAN PENETRATION AT DEPTH



and east slopes show less resistance than south and west slopes. Below 25 cm from the surface resistance becomes high on all slopes and no significant variation is observed between aspects. The variation with depth was found in the field to correspond to the depth of different soil horizons. Especially marked was the increase in resistance at the horizon of accumulation or calcareous horizon.

## 5.3. Soil Moisture Content

Results of laboratory analysis of soil moisture content of samples collected from the top 15 cm of each soil profile are recorded in table V-5. Comparison of values on south and north facing sites reveal consistently lower percentage moisture contents on south facing slopes. East and west slopes display a close relationship in moisture content values. These results are in accord with relationships established by Sellers (1965) and Geiger (1966).

U tests to determine the significance of the observed differences between aspects confirm that north slopes have higher moisture content than south slopes, significant at the 99.9 per cent level (TABLE V-6). Variation between moisture values on south and east, north and west, and west and east slopes is not significant at the 95 per cent level. The results show significant differences in moisture content values between north and south facing slopes, but do not show differences of similar significance for other aspect combinations.

## 5.4. Infiltration Rates

### 5.4.1. Introduction

Two of the most significant characteristics of a soil influencing its erodibility are:

a. Infiltration rate and capacity.

b. Structural stability.

Both are very closely related. Infiltration rates are considered in an attempt to determine the relative expectancy of runoff occurrence on

TABLE V-5. PERCENTAGE MOISTURE CONTENT

(Samples from top 15 cm)

| Mound | North | South | East | West |
|---|---|---|---|---|
| 1 | 16.64 | 9.44 | 11.72 | - |
| 3 | 14.13 | 12.03 | 12.53 | - |
| 5 | 11.28 | 9.95 | 8.17 | - |
| 6 | 12.87 | 10.52 | 10.32 | 9.49 |
| 9 | 18.36 | 11.15 | 11.03 | - |
| 10 | 28.11 | 15.59 | 20.32 | 20.95 |
| 11 | 28.80 | - | 21.70 | 17.99 |
| 13 | 20.14 | 11.46 | 16.36 | 13.08 |
| 16 | 16.00 | 7.22 | - | 6.82 |
| 19 | 17.96 | 6.41 | 12.57 | 13.54 |
| MEAN | 18.42 | 10.42 | 13.86 | 13.64 |

Samples collected on individual mounds on the same day, but mounds were sampled on different days.

TABLE V-6. RESULTS OF MANN-WHITNEY U TESTS FOR DIFFERENCE IN MOISTURE CONTENT WITH ASPECT.

| Hypotheses | $N_1$ | $N_2$ | U Table | Significance Level | Observed U Value | Conclusion |
|---|---|---|---|---|---|---|
| Ho N = S<br>$H_1$ N > S | 9 | 10 | 8 | 0.001 | 5 | Reject Ho |
| Ho N = W<br>$H_1$ N > W | 6 | 10 | 3<br>14 | 0.001<br>0.05 | 18 | Accept Ho |
| Ho W = E<br>$H_1$ W > E | 6 | 9 | 2<br>12 | 0.001<br>0.05 | 26 | Accept Ho |
| Ho S = E<br>$H_1$ S > E | 9 | 9 | 7<br>21 | 0.001<br>0.05 | 27 | Accept Ho |

different aspects. The work of Middleton (1930) and Horton (1933) emphasised that runoff and erosion were directly related to infiltration capacity.

Infiltration is the process by which water enters the soil, though percolation, the movement of water through the soil, is also involved. Horton (1940) observed that rain falling at intensities exceeding the infiltration capacity of soil would produce water on the surface, which may be held by surface retention. As there is little chance of surface retention on the slopes studied excess water will runoff directly.

The close relationship of a number of factors with infiltration has been mentioned by Horton (1940), Musgrave (1955) and Baver (1956). These can be simplified into several categories.

Factors:

i. Permeability of the soil profile - density, pores etc.
ii. Soil surface conditions - compactness, roughness.
iii. Soil moisture content.
iv. Soil protective cover - vegetation.
v. Duration and intensity of rainfall.
vi. Slope.

No attempt was made to isolate these factors but they must be taken into account in any analysis of differences in infiltration rates.

Infiltration data was collected for half of the mounds selected for study. Using a random number table ten mounds were selected for analysis. These were mounds 1, 3, 5, 6, 9, 10, 11, 13, 16, and 19. Infiltration measurements were taken on thirty-four slopes.

### 5.4.2. Results of Infiltration on Individual Mounds

Data for each infiltration is expressed in cm per hour (APPENDIX A). Graphs of infiltration rates on each mound reveal a relatively

consistent pattern with north and west facing slopes recording higher infiltration than east and south slopes (selected examples FIG. 5-2). These differences in infiltration are true for nine of the ten mounds. The exception is mound 5 (FIG. 5-2a), where south and east sites record abnormally high infiltration. Due to the consistency of data recorded for the other mounds it was felt that, in an analysis of mean infiltration rates, the data for mound 5 should be excluded, as the results for mound 5 are an obvious anomaly.

### 5.4.3. Results of Mean Values of Infiltration on each Aspect

Graphs of mean infiltration for each aspect are given (FIG. 5-3 & 5-4). The graphs show by means of vertical lines the range of values on each aspect at the set time intervals. In each case a dramatic drop in infiltration rate in the first 5 to 10 minutes is evident before the rate levels - off, reaching an asymptotic line at a relatively constant infiltration. (Similar curves are described by Horton, 1940; and Verma 1968). In some cases individual infiltration tests demonstrate a secondary peak. The secondary peak commonly occurs after 15 to 20 minutes (FIG. 5-2b). This secondary peak may reflect the influence of horizonation in the soil profile.

A number of parameters have been used in the interpretation of infiltration curves. The time at which the curves start levelling off (tc) can depend upon initial soil moisture, pore geometry, or the swelling of clays. The constant rate which occurs after 40-60 minutes is believed to reflect water movement through the least permeable layer. The infiltration data of this study usually reveal a constant rate after about 45 minutes. Tc does not vary to any great extent. Infiltration in the first minutes is highest on north and west slopes, and south and east slopes show low infiltration. Table V-7 showing mean infiltration after the first and second hour, illustrates the differences found between aspects. Infiltration rate decreases in the following series, north > west > east > south.

FIGURE 5-2a

# INFILTRATION RATES WITH ASPECT

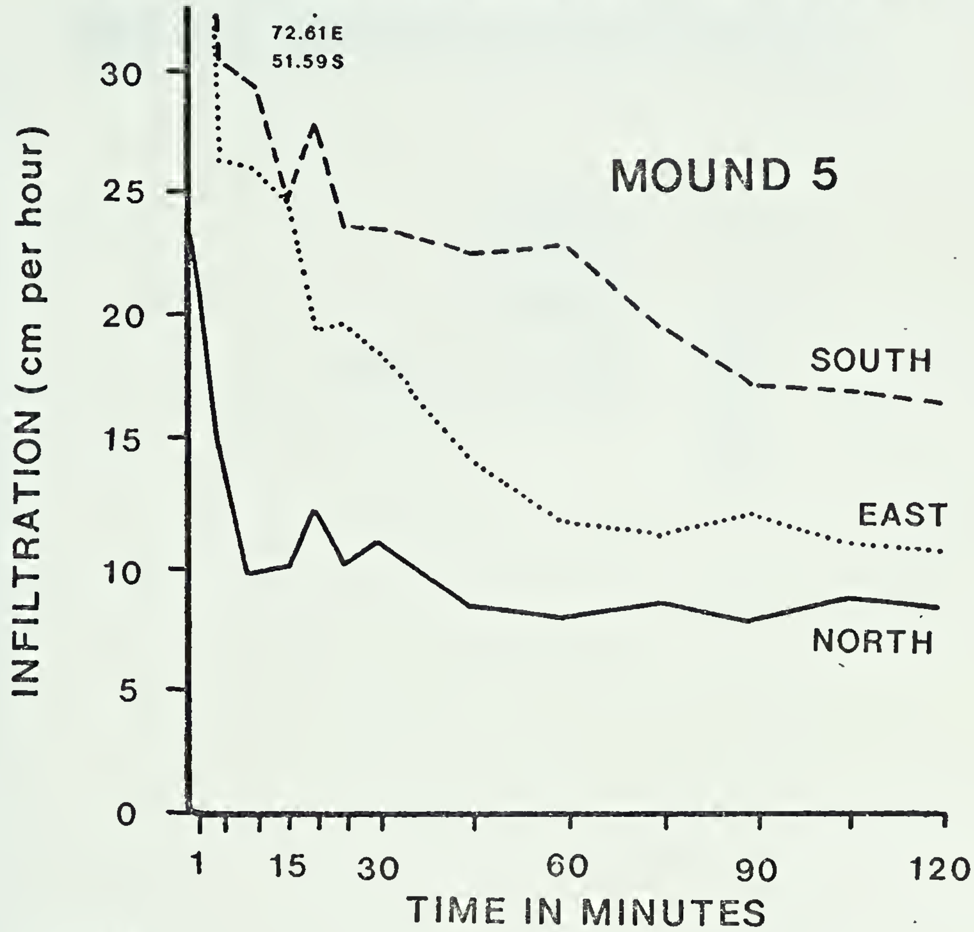



FIGURE 5-2b

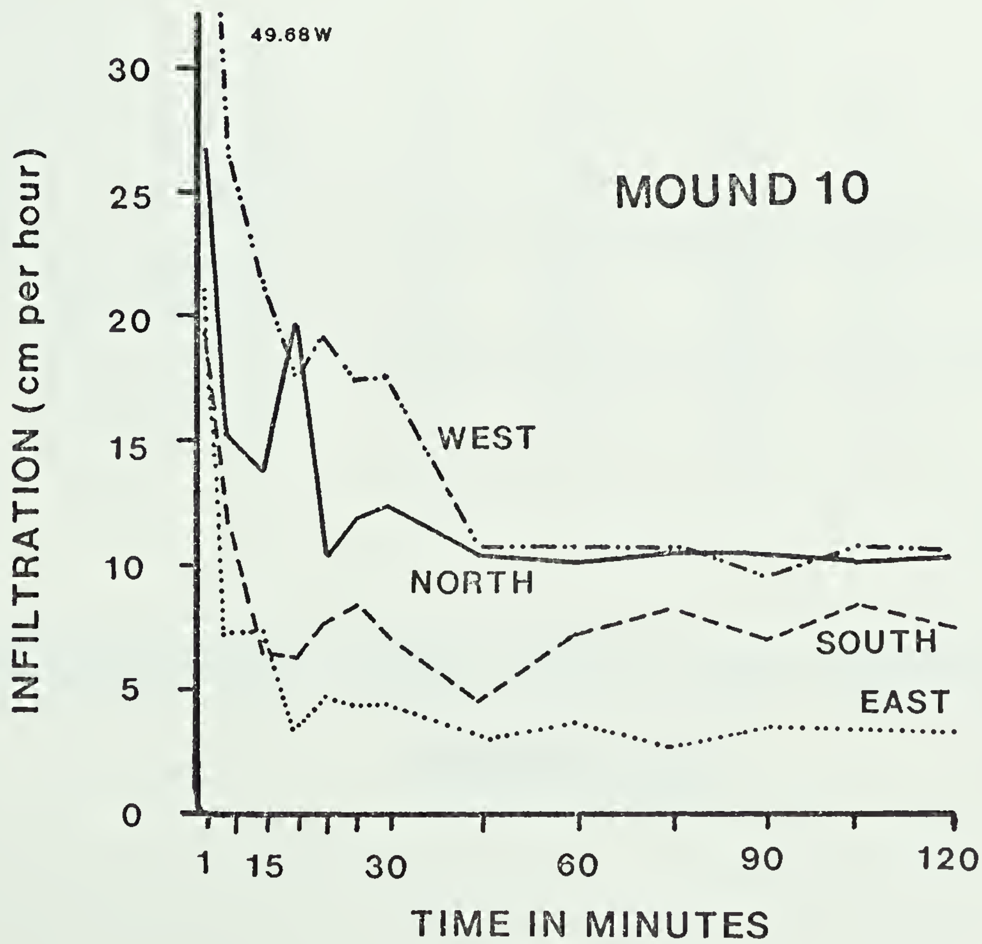


FIGURE 5-3

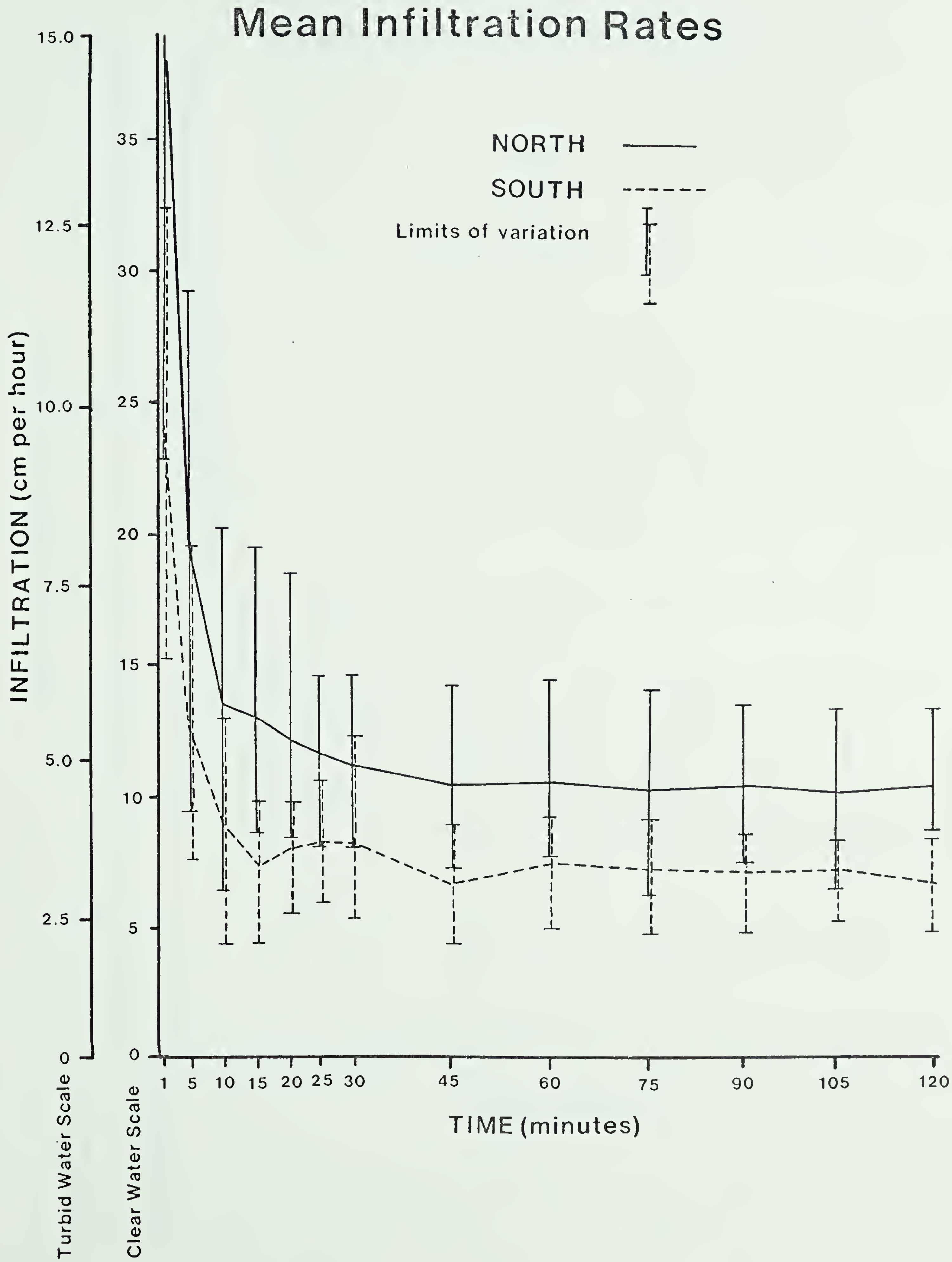

Mean Infiltration Rates
NORTH
SOUTH
Limits of variation
INFILTRATION (cm per hour)
15.0
12.5
10.0
7.5
5.0
2.5
0
35
30
25
20
15
10
5
0
1
5
10
15
20
25
30
45
60
75
90
105
120
TIME (minutes)
Turbid Water Scale
Clear Water Scale

FIGURE 5-4

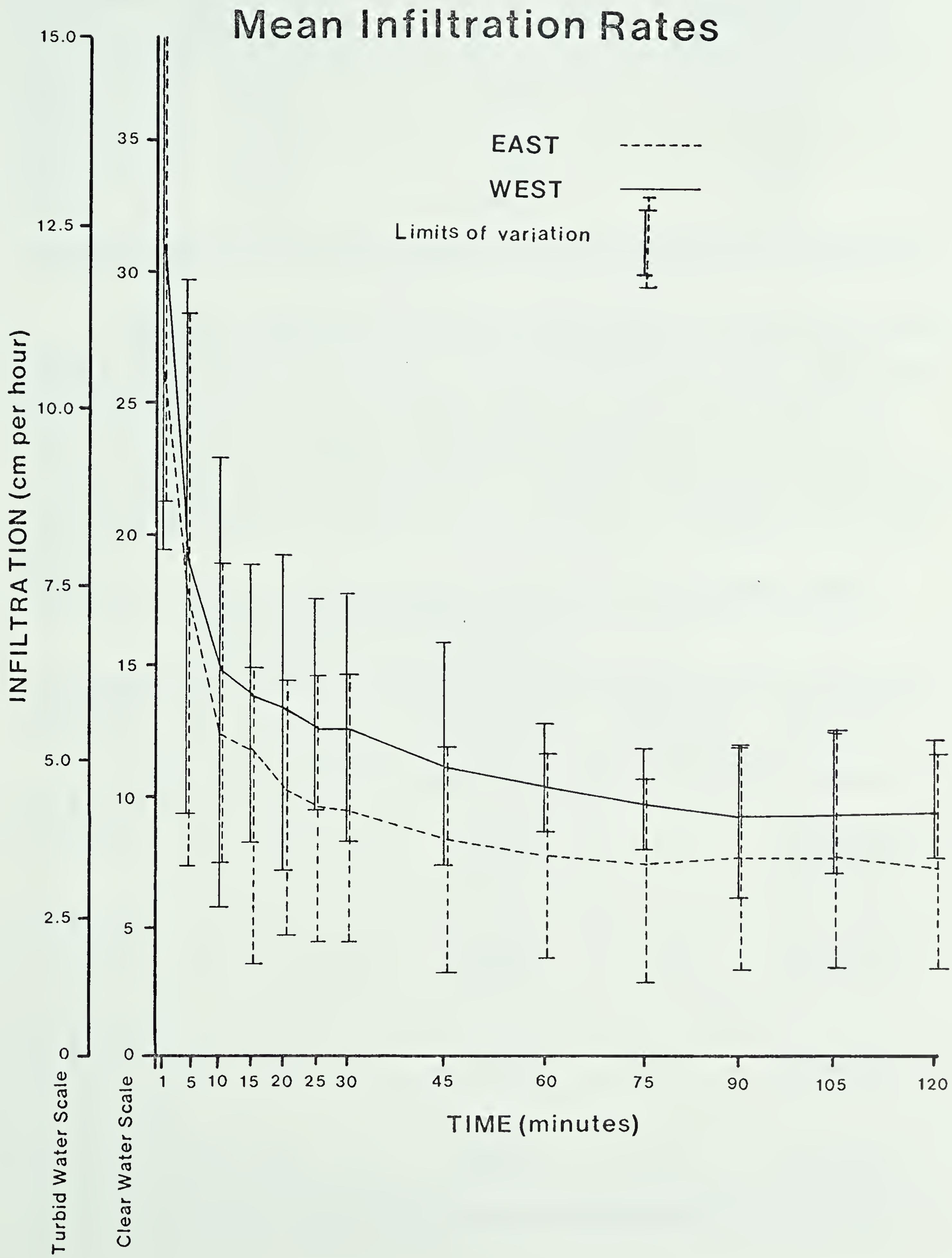

Mean Infiltration Rates
EAST
WEST
Limits of variation
INFILTRATION (cm per hour)
15.0
12.5
10.0
7.5
5.0
2.5
0
35
30
25
20
15
10
5
0
1
5
10
15
20
25
30
45
60
75
90
105
120
TIME (minutes)
Turbid Water Scale
Clear Water Scale

TABLE V-7. AVERAGE INFILTRATION (cm per hour).

| Aspect | After 15 mins. | After 1st hour | After 2nd hour |
|---|---|---|---|
| North | 12.99 | 11.06 | 10.52 |
| South | 7.44 | 7.51 | 6.80 |
| East | 11.80 | 7.44 | 6.92 |
| West | 13.70 | 10.21 | 9.44 |

U tests for significant differences of means of infiltration values measured at 15 minute intervals, for different aspects, show significant differences between north and south aspects at the 95 per cent level, but no significant difference between north and west, south and east, or west and east aspects (TABLE V-8). The only statistically significant difference therefore is between the two extremes of exposure, north and south.

TABLE V-8. RESULTS OF MANN-WHITNEY U TESTS FOR DIFFERENCES IN MEAN INFILTRATION RATES WITH ASPECT.

| Hypotheses | $N_1$ | $N_2$ | U Table | Significance Level | Observed U Value | Conclusion |
|---|---|---|---|---|---|---|
| Ho N = S | | | | | | |
| $H_1$ N > S | 8 | 9 | 5 | 0.001 | 6 | Accept Ho |
| | | | 18 | 0.05 | | Reject Ho |
| Ho N = W | | | | | | |
| $H_1$ N > W | 6 | 9 | 2 | 0.001 | 25 | Accept Ho |
| | | | 12 | 0.05 | | |
| Ho S = E | | | | | | |
| $H_1$ E > S | 8 | 8 | | 0.139 | 21 | Accept Ho |
| Ho W = E | | | | | | |
| $H_1$ W > E | 6 | 8 | | 0.114 | 14 | Accept Ho |

### 5.4.4. Prediction of Possible Runoff in the Area

A basic criticism of the method of estimating infiltration rates is that the tests were made using clear water. Using comparative infiltration with clear water and turbid water under rainfall simulation a correction factor has been developed and used to correct such data (Free et al 1940; Kringold and Beenhouwer 1954). The following relationship was found:

$$Y = 0.545\ X^{0.905}$$

Where: $Y$ = Infiltration in turbid water

$X$ = Infiltration in clear water

When the above correction factor is applied to data for clear water, infiltration rates are effectively halved. Ideally a correction factor should be developed using the soil under study, however it does serve to demonstrate that infiltration values under conditions of actual rainfall in the field would be considerable less than those observed. Baver (1956) commented: "Cylinders tend to maintain a higher infiltration capacity than under natural conditions." Values obtained using cylinders do not take into account the influence of raindrop impact, which tends to seal the soil surface and reduce infiltration.

In order to predict possible runoff it is necessary to have records of rainfall intensity. The closest station with near complete records is Calgary, though in past years records have been kept occasionally at Lacombe and Brooks. As intensities at the three stations compare reasonably well, the data from Calgary are used to obtain some indication of rainfall intensity expected in this region. Monthly data are available for most months between 1961-70. Data used are the 5, 15 and 60 minute intensities, expressed in cm per hour (TABLE V-9). The table reveals storms occur mostly in June and July. One hour intensities at no time exceeded 3.7 cm per hour, which by comparison with the values of Fig. 5-3 leaves little likelihood of runoff. Using values of infiltration for shorter time intervals runoff becomes more probable. On three occasions the equivalent intensity was greater than 6.4 cm per hour, with a maximum of between 9 and 10.2 cm per hour.

TABLE V-9. FREQUENCY OF MONTHLY MAXIMUM RAINFALL INTENSITIES

(Intensity cm per hr.)

| (a) Five Min. Maxima | 1.2 | 1.2-2.4 | 2.5-3.7 | 3.8-5.0 | 5.1-6.3 | 6.4-7.6 | 7.7-8.9 | 9.0-10.2 | 10.3-11.5 |
|---|---|---|---|---|---|---|---|---|---|
| May | 2 | 5 | 2 | | | | | | |
| June | 0 | 3 | 2 | 3 | 0 | 0 | 0 | 0 | 1 |
| July | 0 | 3 | 1 | 0 | 0 | 1 | 0 | 2 | |
| Aug. | 1 | 5 | 4 | | | | | | |
| Sept. | 3 | 5 | | | | | | | |
| Cumulative Total | 6 | 27 | 36 | 39 | 39 | 40 | 40 | 42 | 43 |
| (b) Fifteen Min. Maxima | | | | | | | | | |
| May | 7 | 2 | | | | | | | |
| June | 3 | 2 | 3 | | | | | | |
| July | 1 | 3 | 1 | 0 | 0 | 1 | 1 | 1 | |
| Aug. | 6 | 3 | 1 | | | | | | |
| Sept. | 7 | 1 | | | | | | | |
| Cumulative Total | 24 | 35 | 40 | 40 | 40 | 41 | 42 | 43 | |
| (c) Sixty Min. Maxima | | | | | | | | | |
| May | 9 | | | | | | | | |
| June | 8 | | | | | | | | |
| July | 3 | 3 | 2 | | | | | | |
| Aug. | 10 | | | | | | | | |
| Sept. | 8 | | | | | | | | |
| Cumulative Total | 38 | 41 | 43 | | | | | | |

Source: Monthly Record 1961-70 Department of Transport Meteorological Branch.

Infiltration graphs using clear water scale (Figs. 5-3 & 5-4) suggest that rainfall of these intensities would result in runoff on south and east facing slopes, but not north and west slopes. If the turbid water scale is used runoff is possible on all aspects, though it is more probable on south and east slopes. Research on prairie storms has revealed that rainfall intensity in thunderstorms is highest early in the storm (Verma 1968). Highest intensities then occur when the soil surface is most able to absorb the rainfall. If high intensity rainfall occurs after the soil reaches saturation, runoff is inevitable. It would appear then that in this area the chance of runoff capable of excessive erosion may occur only during one storm in a period of several years. The data suggests that if runoff does occur, the likelihood of it occurring on any particular aspect will correspond to the following series, south > east > west > north.

## 5.5. Soil Aggregation

### 5.5.1. Introduction

A second characteristic affecting erodibility is soil structure, and the ability of the soil to form aggregates. Resistance of surface aggregates to the effects of raindrop impact controls the susceptibility of the soil to slope wash and flowage in suspension. Larger sized aggregates remain *in situ* if runoff is not excessive. Three parameters are adopted to evaluate soil aggregation.

1. Percentage water stable aggregate (w.s.a.)
2. Coefficient of aggregation
3. Percentage slaking loss

1. Percentage water stable aggregate

Percentage water stable aggregate is a measure of the relative structural stability of the soil.

Water stable aggregates are held firmly by cementation, such that dispersion, after agitation in water, is prevented. There is a distinction between water stable aggregation and flocculation. Flocculation may aid aggregation initially, but if cementing agents

are absent aggregates will be unstable.

Certain factors which are thought to determine the degree of aggregation on differing aspects act in opposing directions. Where soils have developed on north facing slopes it is assumed that organic content is higher, thereby aiding aggregate stability (Buckman and Brady 1960, p. 59), but moisture content is normally higher, presumably resulting in a marked decrease in aggregate stability (Gish and Browning 1948). Resultant aggregation will depend on the relative importance of each factor.

2. Coefficient of Aggregation

The basic flaw in analysis of water stable aggregates is that no measure of the surface area of the aggregate is taken into account (Scholler and Stockinger, 1953; and Bryan, 1969). However, results from other work suggests that the coefficient of aggregation, as described by Retzer and Russell (1941), gives a fair measure of dispersion. The coefficient is based on the total surface area per unit weight of soil. Soils having the highest coefficient are the best aggregated. The assumptions are that all aggregates have the same average density and the same average configuration, and that the diameters of the aggregates are linearly distributed between the diameters of the openings of the screen sizes.

3. Percentage Slaking Loss

This measure is the difference in percentage aggregate of the dry soil and wet soil, and is therefore a measure of loss with soil wetting. Degree of slaking depends on the type of clay mineral present, and on the occurrence of excessive pressure exerted by entrapped air in the pore spaces of individual aggregates (Yoder 1936).

### 5.5.2. Results of Aggregate Analysis

Weights of aggregates from both wet and dry sieving are expressed as percentages of the original sample. A total of 70 soil samples were analysed and percentage values in each of the four size categories (3 mm, 2 mm, 1 mm, and 0.5 mm), were prepared for both wet and dry runs.

The raw data show a reasonably consistent bimodal pattern with two maxima in the largest and smallest size categories (3 mm and 0.5 mm). With few exceptions the lowest percentages are recorded in the 3 to 2 mm range.

Histograms of mean aggregation size in each category are given for each aspect and show the data for both wet and dry runs (FIG. 5-5). Aggregate size categories from 1 mm to 0.5 mm show little mean variation with aspect. The largest variation is evident in the larger aggregate category > 3 mm. Soils on northern aspects have a mean aggregate > 3 mm of 24.0 per cent while samples from southerly aspects have a mean of 13.8 per cent of the total sample. East and west slopes have mean values of 16.4 per cent and 21.2 per cent respectively. The samples from north facing slopes consistently record higher mean aggregation for each size category (FIG. 5-5) than the samples from other aspects. The high percentages of large aggregates show that the soils of the study area are structurally fairly stable.

For soils of each aspect cumulative percentages of aggregates coarser than each category are presented in table V-10. The same results are presented graphically in figure 5-6.

TABLE V-10. MEAN CUMULATIVE AGGREGATE
(as a percentage of the original sample)

| Aspect | > 3 mm | > 2 mm | > 1 mm | > 0.5 mm |
|---|---|---|---|---|
| North | 24.096 | 30.110 | 40.551 | 54.169 |
| South | 13.809 | 18.725 | 27.630 | 37.899 |
| East | 16.430 | 22.116 | 30.774 | 44.219 |
| West | 21.259 | 27.277 | 37.586 | 51.070 |

Soils on north facing slopes in each case have the highest percentage water stable aggregates, while south facing slopes are consistently lowest. The table shows that soils on northern aspects have higher percentage water stable aggregates and therefore a tendency towards

FIGURE 5-5

PERCENTAGE MEAN AGGREGATION AND ASPECT

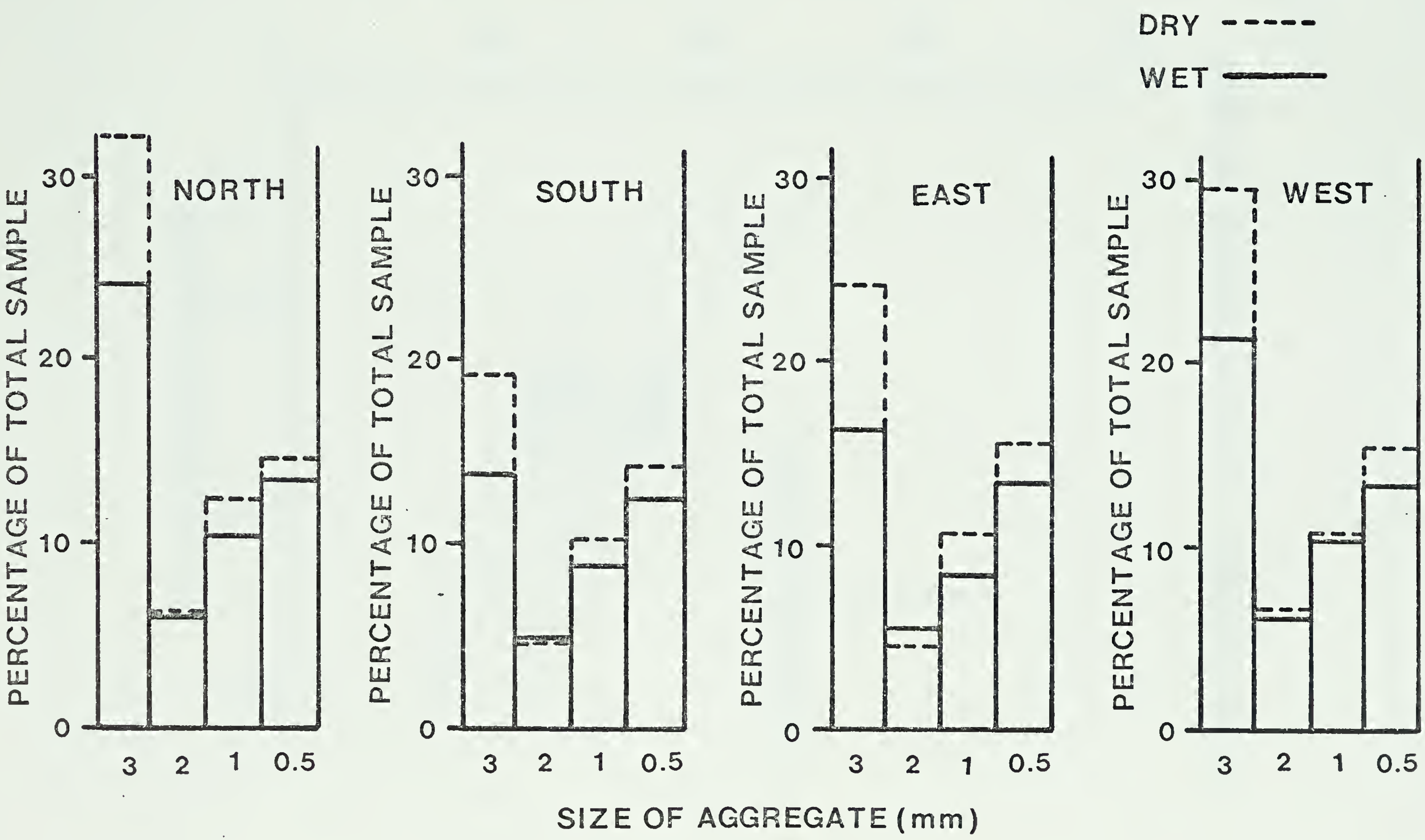
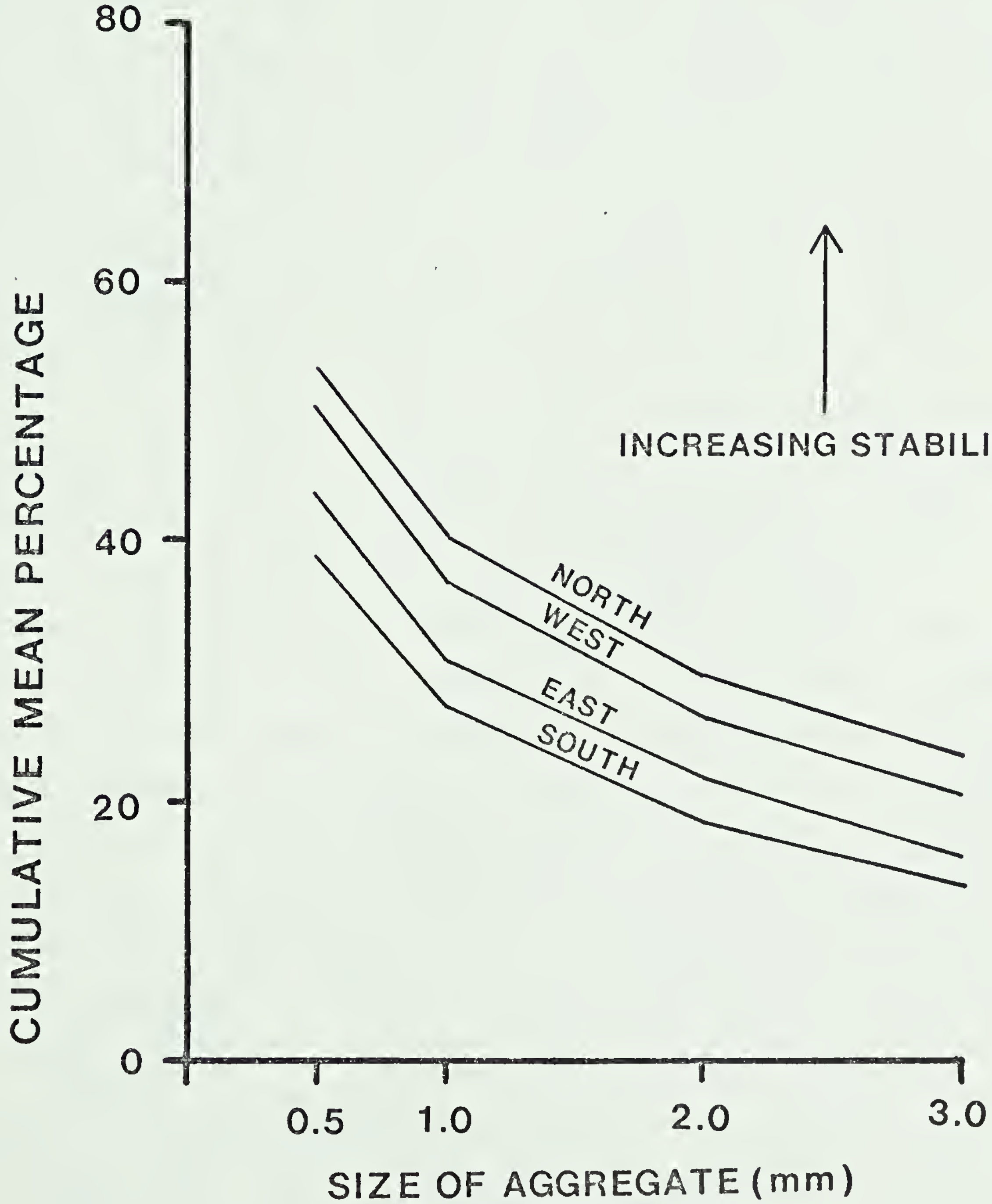


FIGURE 5-6

## MEAN CUMULATIVE AGGREGATE



greater stability. Table V-10 of mean cumulative aggregate shows that aggregation on different aspects can be expressed in a series of decreasing aggregation, north > west > east > south.

The mean value is not always the best parameter to use in a comparison of such results. Graphs of percentage aggregation for each sample according to aspect are given (FIG. 5-7). These have been plotted together for visual comparison (TABLE V-11 & V-12). The graphs reveal considerable differences in values within each aspect. For w.s.a. > 0.5 mm soils on northern aspects range from 64.1 per cent to 39.4 per cent, southern soils from 56.7 per cent to 26.5 per cent, eastern soils from 65.7 per cent to 25.5 per cent and western soils from 61.1 per cent to 38.5 per cent. In addition to the apparent differences between aspects demonstrated on these graphs, there are considerable differences within each aspect. W.s.a. > 2 mm shows basically the same pattern. The very wide variation within aspects may be due to some analytical inaccuracy or more probably it may reflect real variability associated with the different times of sampling. The fluctuation of the results on each aspect may be explained by seasonality. The samples were collected during a period of more than two months in spring and early summer 1971. Rennie et al (1954) attempted to describe seasonal variation of aggregation by taking bi-monthly samples at three sites. They found evidence for marked seasonal change. Gish and Browning (1948) also mention the importance of soil moisture at the time of sampling and its effect on aggregation. They noticed that an increase in soil moisture was accompanied by a decrease in aggregation. Despite the wide variation it is apparent from the graph, figure 5-7, that the general trend of aggregation values is similar to that revealed by calculation of the mean values. Arrangement of aspect with decreasing values of aggregation gives the sequence north, west, east, and south. Deviation from this pattern may have been caused by disturbance of the soil samples in the field or in transit to the laboratory: e.g. Mound 15 north has only 11.2 per cent w.s.a. > 2 mm while the mean value for north slopes is 54.1 per cent.

## PERCENTAGE WATER STABLE AGGREGATE FOR-EACH ASPECT

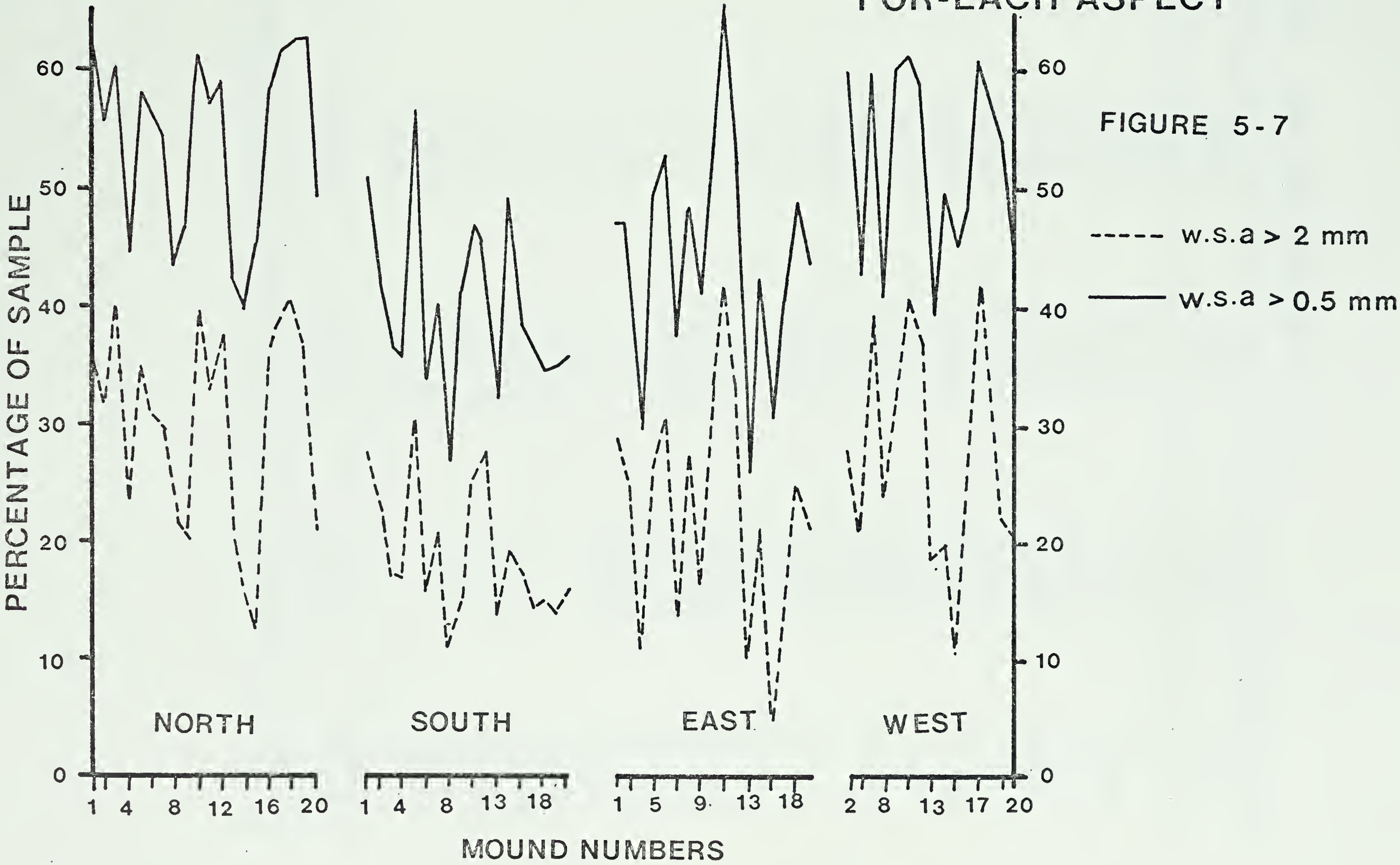



FIGURE 5-7

TABLE V-11. WATER STABLE AGGREGATE >0.5 mm

| Mound | North | South | East | West |
|---|---|---|---|---|
| 1 | 63.927 | 50.765 | 46.723 | - |
| 2 | 55.746 | 43.321 | - | 50.973 |
| 3 | 60.413 | 36.420 | 46.687 | - |
| 4 | 44.574 | 35.692 | 29.341 | 42.143 |
| 5 | 58.542 | 56.737 | 49.301 | - |
| 6 | 56.341 | 33.829 | 52.562 | 69.534 |
| 7 | 54.427 | 40.082 | 37.169 | - |
| 8 | 43.235 | 26.521 | 48.099 | 40.331 |
| 9 | 46.861 | 41.190 | 40.867 | - |
| 10 | 61.308 | 46.986 | 51.638 | 59.982 |
| 11 | 57.149 | - | 65.729 | 61.132 |
| 12 | 59.186 | 45.894 | 52.691 | 58.644 |
| 13 | 42.129 | 31.902 | 25.596 | 38.586 |
| 14 | 39.405 | 49.206 | 49.032 | 49.187 |
| 15 | 44.994 | - | 30.092 | 44.344 |
| 16 | 58.575 | 38.289 | - | 48.685 |
| 17 | 61.619 | 36.446 | 40.939 | 60.566 |
| 18 | 62.624 | 34.210 | 48.779 | 56.791 |
| 19 | 62.670 | 34.946 | 43.488 | 50.328 |
| 20 | 49.490 | 35.753 | - | 44.725 |
| MEAN | 54.160 | 39.899 | 44.219 | 51.070 |

TABLE V-12. WATER STABLE AGGEGATE >2 mm

| Mound | North | South | East | West |
|---|---|---|---|---|
| 1 | 36.325 | 27.475 | 28.650 | - |
| 2 | 31.333 | 23.366 | - | 27.623 |
| 3 | 40.570 | 17.381 | 25.132 | - |
| 4 | 23.275 | 16.843 | 10.732 | 20.363 |
| 5 | 34.998 | 30.905 | 25.424 | - |
| 6 | 31.248 | 15.207 | 30.408 | 38.930 |
| 7 | 29.794 | 20.581 | 13.510 | - |
| 8 | 22.059 | 10.040 | 27.321 | 22.966 |
| 9 | 20.212 | 14.306 | 15.173 | - |
| 10 | 39.987 | 25.020 | 29.415 | 33.632 |
| 11 | 33.217 | - | 41.753 | 40.252 |
| 12 | 37.743 | 27.309 | 32.029 | 37.166 |
| 13 | 21.001 | 13.685 | 9.661 | 18.900 |
| 14 | 15.272 | 19.051 | 21.168 | 19.472 |
| 15 | 11.282 | - | 4.468 | 9.392 |
| 16 | 36.118 | 17.779 | - | 24.875 |
| 17 | 39.396 | 14.174 | 15.032 | 41.402 |
| 18 | 40.903 | 14.860 | 24.248 | 32.924 |
| 19 | 36.338 | 13.604 | 21.854 | 21.779 |
| 20 | 21.134 | 15.479 | - | 20.293 |
| MEAN | 30.110 | 18.725 | 22.116 | 27.277 |

5.5.3. Coefficient of Aggregation (c.a.)

The coefficient used is based on that adopted by Retzer and Russell (1941).

$$\text{c.a.} = \sum \frac{\text{Percentage Weight of aggregation for each category}}{\text{Average Diameter}}$$

Average diameters for the sieve sizes used are as follows:

| Sieve Openings | | Aver. Diameter |
|---|---|---|
| 8 mm - 3 mm | - | 5.5 mm |
| 3 mm - 2 mm | - | 2.5 mm |
| 2 mm - 1 mm | - | 1.5 mm |
| 1 mm - 0.5 mm | - | 0.75 mm |

Results for the twenty mounds are presented in table V-13. More stable soils demonstrate the highest coefficients, while soils of lower stability are represented by lower values. North and west soils show a tendency once again to be more stable, exceptions being mounds 5, 8, 11, 14, and 18. The data are ranked to clarify possible differences and presented graphically on figure 5-8. The graph and tabulated mean values below reveal that north and west slopes have higher aggregation coefficients.

Mean Values - Coefficient of Aggregation

| | |
|---|---|
| North | 31.926 |
| South | 26.771 |
| East | 28.954 |
| West | 31.184 |

When surface area of the aggregates is taken into consideration, the pattern of differences revealed using percentage weights (5.5.2) is confirmed, even though use of the coefficient of aggregation analysis minimizes the effect of the larger aggregates.

5.5.4. Percentage Slaking Index

The slaking index is the difference between percentage aggregate produced by wet sieving and the percentage produced by dry sieving. Any loss reflects the percentage of the aggregate which is unstable in water. Losses are categorised for each aspect and mean values

TABLE V-13. COEFFICIENT OF AGGREGATION (as a percentage of the total sample)

| Mound | North | South | East | West |
|---|---|---|---|---|
| 1 | 35.381 | 30.693 | 25.860 | - |
| 2 | 32.372 | 26.084 | - | 30.039 |
| 3 | 29.373 | 24.179 | 27.389 | - |
| 4 | 28.519 | 24.898 | 24.149 | 28.200 |
| 5 | 32.412 | 34.448 | 32.014 | - |
| 6 | 33.634 | 22.859 | 30.488 | 29.616 |
| 7 | 32.716 | 24.992 | 28.860 | - |
| 8 | 27.561 | 19.907 | 27.726 | 23.177 |
| 9 | 32.770 | 31.179 | 30.124 | - |
| 10 | 30.419 | 28.433 | 29.977 | 35.916 |
| 11 | 32.991 | - | 33.452 | 30.122 |
| 12 | 29.536 | 24.715 | 28.768 | 30.992 |
| 13 | 28.038 | 22.683 | 19.927 | 25.622 |
| 14 | 29.571 | 36.581 | 29.537 | 35.815 |
| 15 | 39.298 | - | 29.623 | 38.830 |
| 16 | 30.780 | 26.206 | - | 31.798 |
| 17 | 31.574 | 27.575 | 31.264 | 28.528 |
| 18 | 31.055 | 24.048 | 35.625 | 33.126 |
| 19 | 35.800 | 26.365 | 27.525 | 35.158 |
| 20 | 34.722 | 26.042 | - | 30.823 |
| MEAN | 31.926 | 26.771 | 28.954 | 31.184 |

FIGURE 5-8

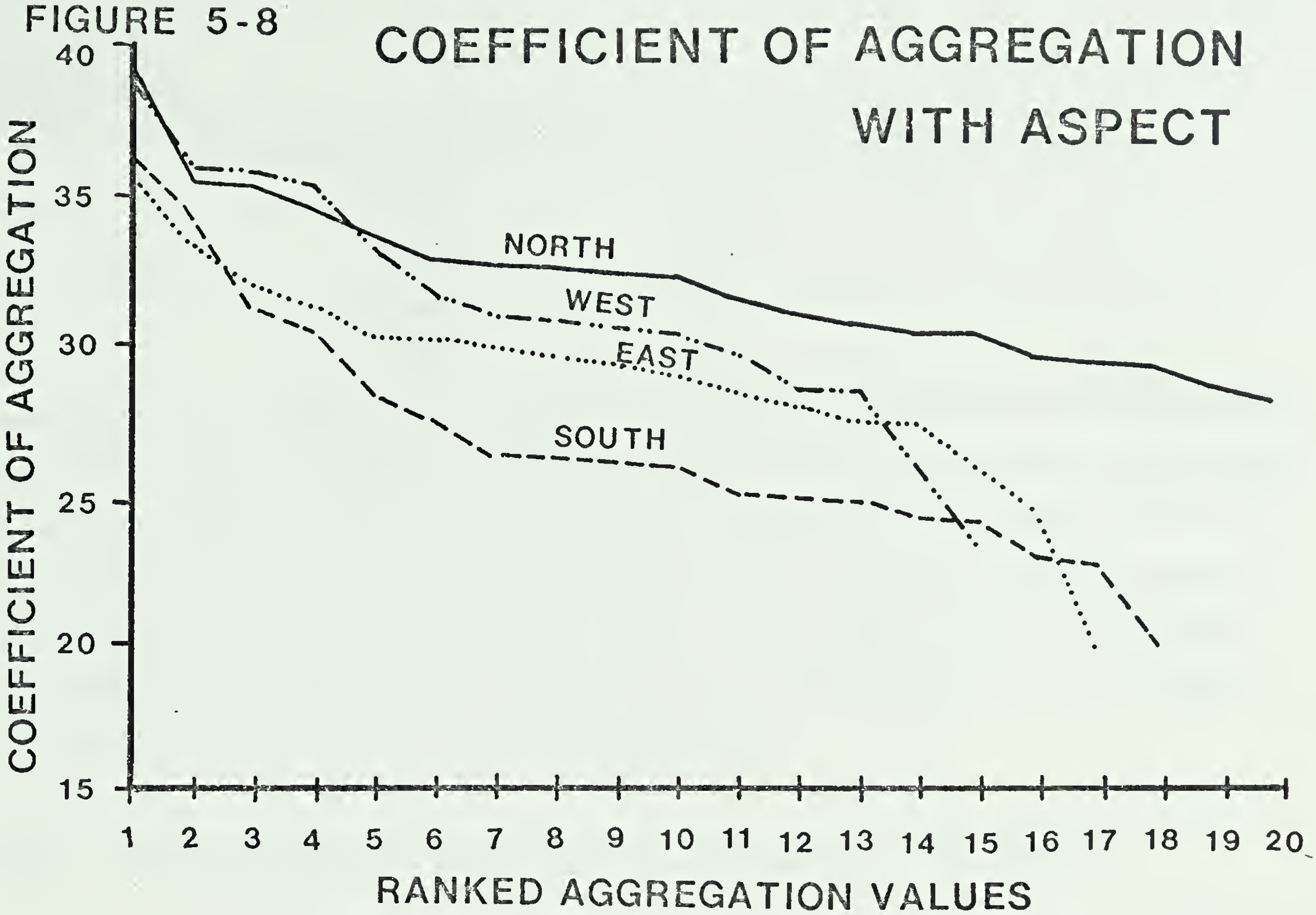
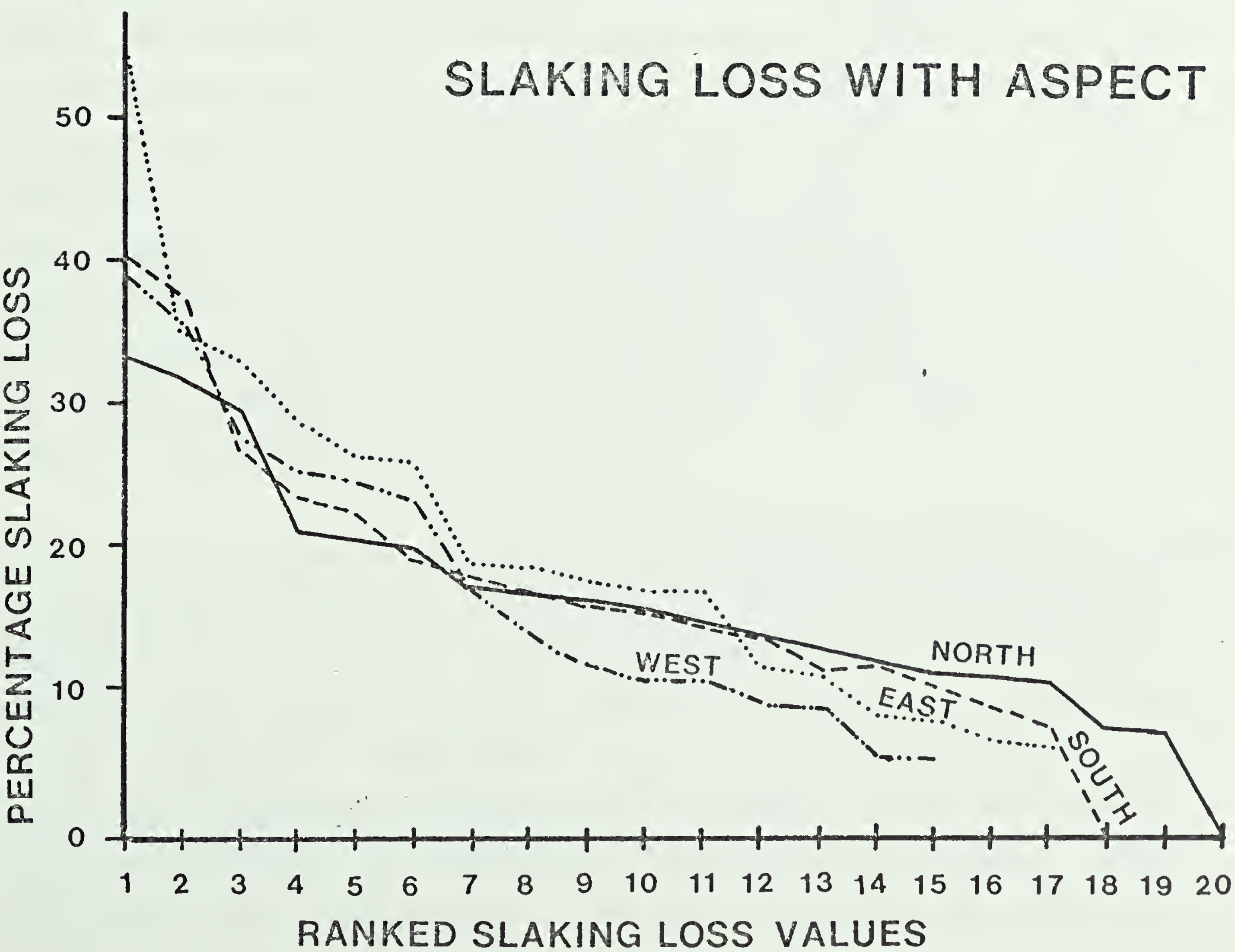



FIGURE 5-9



determined:

Mean Values Slaking Loss (as a percentage)

| | |
|---|---|
| North | 16.5 |
| South | 17.7 |
| East | 20.5 |
| West | 18.0 |

Mean values of slaking loss reveal a slightly greater loss on east slopes and south slopes compared to north. Graphs of the values for each aspect are drawn using the data from table V-14. The data are ranked for ease of comparison. The graphs indicate that the values for slaking loss on each aspect are very similar (FIG. 5-9). The results serve to confirm the comments of Bryan (1971) who doubted the efficiency of the slaking loss as a general index of soil erodibility.

5.5.5. Significance of Differences in Aggregation with Aspect

Tests of the validity of the collected data are essential to support what has been demonstrated graphically. A Mann-Whitney U test is used to determine the significance of differences for the results of the parameters used in the analysis, w.s.a. > 0.5 mm, w.s.a. > 2 mm, coefficient of aggregation, and slaking loss, between aspects. The first hypothesis (Ho), in each case is that differences between two groups of data from different aspects under analysis are due to chance. Ho is rejected if the observed value of U is less than the value obtained from tables. Results are summarized in table V-15. Significance levels are set at 0.001 and 0.05.

The tests serve to confirm earlier deductions. Slaking loss proves to be the least valuable of the parameters indicating differences of aggregation between aspects. This index indicates no significant difference with change in aspect on any of the four tests at both the 0.001 and 0.05 level. The results for the other three parameters consistently reject the hypothesis (TABLE V-15A) that differences in aggregation on north and south facing slopes are due to chance. The difference between values of each parameter for north and south facing

TABLE V-14. LOSS DUE TO SLAKING (as a percentage of the total sample)

| Mound | North | South | East | West |
|---|---|---|---|---|
| 1 | 29.336 | 16.233 | 18.034 | - |
| 2 | 16.823 | 16.656 | - | 25.574 |
| 3 | 7.790 | 14.305 | 19.233 | - |
| 4 | 20.722 | 22.037 | 34.646 | 25.053 |
| 5 | 14.659 | 12.147 | 17.710 | - |
| 6 | 21.138 | 36.872 | 26.201 | 9.295 |
| 7 | 12.686 | 18.014 | 26.013 | - |
| 8 | 31.541 | 7.932 | 6.439 | 11.494 |
| 9 | 7.695 | 9.388 | 7.093 | - |
| 10 | 11.104 | 15.105 | 17.763 | 9.907 |
| 11 | 16.010 | - | 11.814 | 17.588 |
| 12 | 13.662 | 12.109 | 8.239 | 11.451 |
| 13 | 32.851 | 39.780 | 53.988 | 35.036 |
| 14 | 15.289 | 0.864 | 8.715 | 5.955 |
| 15 | 0.686 | - | 28.747 | 23.221 |
| 16 | 11.983 | 10.769 | - | 12.227 |
| 17 | 17.753 | 19.283 | 12.027 | 5.501 |
| 18 | 17.426 | 17.524 | 19.124 | 14.431 |
| 19 | 20.281 | 26.446 | 32.729 | 38.247 |
| 20 | 11.677 | 23.217 | - | 27.123 |
| MEAN | 16.555 | 17.704 | 20.500 | 18.073 |

TABLE V-15. RESULTS OF MANN-WHITNEY U TESTS FOR DIFFERENCES OF SOIL AGGREGATION WITH ASPECT

A. Ho : N = S

$H_1$ : N > S

Where: $n_1 = 18$ $n_2 = 20$

| Index of Aggregation | U Table | Significance Level | Observed U Value | Conclusion |
|---|---|---|---|---|
| w.s.a. > 0.5 mm | 76 | 0.001 | 28 | Reject Ho |
| w.s.a. > 2.0 mm | 76 | 0.001 | 55 | Reject Ho |
| Coeff. of Aggregation | 76 | 0.001 | 49 | Reject Ho |
| Slaking Loss | 76 | 0.001 | 191 | Accept Ho |
| | 123 | 0.05 | | Accept Ho |

B. Ho : N = W

$H_1$ : N > W

Where: $n_1 = 15$ $n_2 = 20$

| Index of Aggregation | U Table | Significance Level | Observed U Value | Conclusion |
|---|---|---|---|---|
| w.s.a. > 0.5 mm | 59 | 0.001 | 117 | Accept Ho |
| | 100 | 0.05 | | Accept Ho |
| w.s.a. > 2.0 mm | 59 | 0.001 | 125 | Accept Ho |
| | 100 | 0.05 | | Accept Ho |
| Coeff. of Aggregation | 59 | 0.001 | 137 | Accept Ho |
| | 100 | 0.05 | | Accept Ho |
| Slaking Loss | 59 | 0.001 | 149 | Accept Ho |
| | 100 | 0.05 | | Accept Ho |

C. Ho : E = S

$H_1$ : E > S

Where; $n_1 = 17$ $n_2 = 18$

| Index of Aggregation | U Table | Significance Level | Observed U Value | Conclusion |
|---|---|---|---|---|
| w.s.a. > 0.5 mm. | 61 | 0.001 | 105 | Accept Ho |
| | 102 | 0.05 | | Accept Ho |
| w.s.a. > 2.0 mm. | 61 | 0.001 | 110 | Accept Ho |
| | 102 | 0.05 | | Accept Ho |
| Coeff. of Aggregation | 61 | 0.001 | 93 | Accept Ho |
| | 102 | 0.05 | | Reject Ho |
| Slaking Loss | 61 | 0.001 | 138 | Accept Ho |
| | 102 | 0.05 | | Accept Ho |

D. Ho : W = E

$H_1$ : W > E

Where; $n_1 = 15$ $n_2 = 17$

| Index of Aggregation | U Table | Significance Level | Observed U Value | Conclusion |
|---|---|---|---|---|
| w.s.a. > 0.5 mm. | 47 | 0.001 | 77 | Accept Ho |
| | 83 | 0.05 | | Reject Ho |
| w.s.a. > 2.0 mm. | 47 | 0.001 | 96 | Accept Ho |
| | 83 | 0.05 | | Accept Ho |
| Coeff. of Aggregation | 47 | 0.001 | 87 | Accept Ho |
| | 83 | 0.05 | | Accept Ho |
| Slaking Loss | 47 | 0.001 | 112 | Accept Ho |
| | 83 | 0.05 | | Accept Ho |

slopes is highly significant at the 0.001 level. A comparison of aggregation on north and west facing slopes (TABLE V-15B) reveals that any differences here are due to chance as Ho is accepted at a high level of significance. Similarly, differences between values for south and east slopes are not accepted as significant. An exception to the acceptance of Ho occurs for the coefficient of aggregation which shows significant differences between values for south and east facing slopes at the 0.05 level, though not at the 0.001 level. W.s.a. $>$0.5 mm is the only index showing significant differences between west and east values at the 0.05 level.

The index of w.s.a. $>$0.5 mm shows the most distinct contrast between aspects and slaking loss values show least contrast between aspects. In conclusion the tests of significance show that at the 0.001 level greater aggregation, and hence greater soil stability, occurs on soils developed on north facing slopes as opposed to south and east aspects. However no significant difference at the 0.001 level can be detected between values of aggregation recorded on south and east facing slopes or north and west facing slopes. The results for the coefficient of aggregation permit acceptance of the hypothesis that aggregation on east slopes is greater than on south slopes at the 0.05 level of significance. Results for w.s.a. $>$0.5 mm permit acceptance of the hypothesis that aggregation on west slopes is greater than aggregation on east slopes, also at the 0.05 level of significance.

## 5.6. Grain Size Distribution

### 5.6.1. Introduction

Grain size data are expressed according to the British Standard Code of Practice; sand 0.06 mm to 2.0 mm diameter, and silt 0.002 mm to 0.06 mm. For detailed analysis a logarithmic scale is used to aid statistical description. The data are plotted against a percentage finer cumulative scale. In order to measure skewness the median value, ($Q_2$ according to Trask, 1952), is taken as the value in millimeters of the 50th percentile on the cumulative frequency graph. Trask's formula

for skewness is used in preference to Folk and Ward's because the open ended nature of the curves makes determination less than the 20th percentile impossible without extrapolation. The formula used for skewness is:

$$Sk = \frac{Q_1 \times Q_3}{Md^2}$$

Where: $Q_1$ = Upper quartile value in mm

$Q_3$ = Lower quartile value in mm

$Md$ = Median value in mm

Skewness values above 1.0 indicate a tail of coarse material and less than 1.0 a tail of fine material.

### 5.6.2. Results of Grain Size Analysis

Size differentiation into sand, silt and clay sizes reveals that surface soil samples are composed of more than 50 per cent sand size particles, with silt percentages ranging from 30.1 per cent to 32.2 per cent and clay content from 15.6 per cent to 18.4 per cent. Decrease in percentage sand content with depth is consistently recorded. Samples taken from below the Ca layer on the soil profiles contain clay contents ranging from 25.2 per cent to 27.1 per cent. On the basis of the size distribution, soils of this area could be described as loam, or sandy loam. Differences of values between aspects appears minimal. South facing slopes record marginally higher sand content and the clay content is marginally higher on east and west slopes. In all cases the range of values between aspects for any one size class is only 2 to 5 per cent (TABLE V-16).

U tests of significant differences between aspects support the above qualitative assessment (TABLE V-17). Percentage sand content between chosen aspects is tested and the hypothesis that any differences are due to chance is accepted for all four tests. Consequently it seems that textural distributions do not vary significantly with change in aspect.

TABLE V-16. SIZE DIFFERENTIATION

(Mean values percentage sand, silt and clay)

| | Sand | Silt | Clay |
|---|---|---|---|
| Surface soil | | | |
| North | 51.844 | 32.250 | 15.906 |
| South | 54.105 | 30.198 | 15.697 |
| East | 51.236 | 30.352 | 18.412 |
| West | 53.624 | 28.384 | 17.992 |
| Samples at depth | | | |
| North | 47.064 | 28.437 | 24.499 |
| South | 43.434 | 31.065 | 25.501 |
| East | 45.718 | 31.031 | 23.251 |
| West | 46.419 | 26.845 | 26.736 |
| Samples at calcareous layer | | | |
| North | 43.662 | 29.153 | 27.185 |
| South | 40.613 | 32.804 | 26.583 |
| East | 42.800 | 31.628 | 25.572 |
| West | 45.610 | 29.145 | 25.245 |

TABLE V-17. RESULTS OF MANN-WHITNEY U TESTS FOR DIFFERENCES IN PERCENTAGE SAND CONTENT WITH ASPECT.

| Hypotheses | $N_1$ | $N_2$ | U Table | Significance Level | Observed U Value | Conclusion |
|---|---|---|---|---|---|---|
| Ho N = S | | | | | | |
| $H_1$ N > S | 9 | 10 | 8 | 0.001 | 37 | Accept Ho |
| | | | 24 | 0.05 | | |
| Ho N = W | | | | | | |
| $H_1$ N > W | 6 | 10 | 3 | 0.001 | 23 | Accept Ho |
| | | | 14 | 0.05 | | |
| Ho S = E | | | | | | |
| $H_1$ E > S | 9 | 9 | 7 | 0.001 | 25 | Accept Ho |
| | | | 21 | 0.05 | | |
| Ho W = E | | | | | | |
| $H_1$ W > E | 6 | 9 | 2 | 0.001 | 19 | Accept Ho |
| | | | 12 | 0.05 | | |

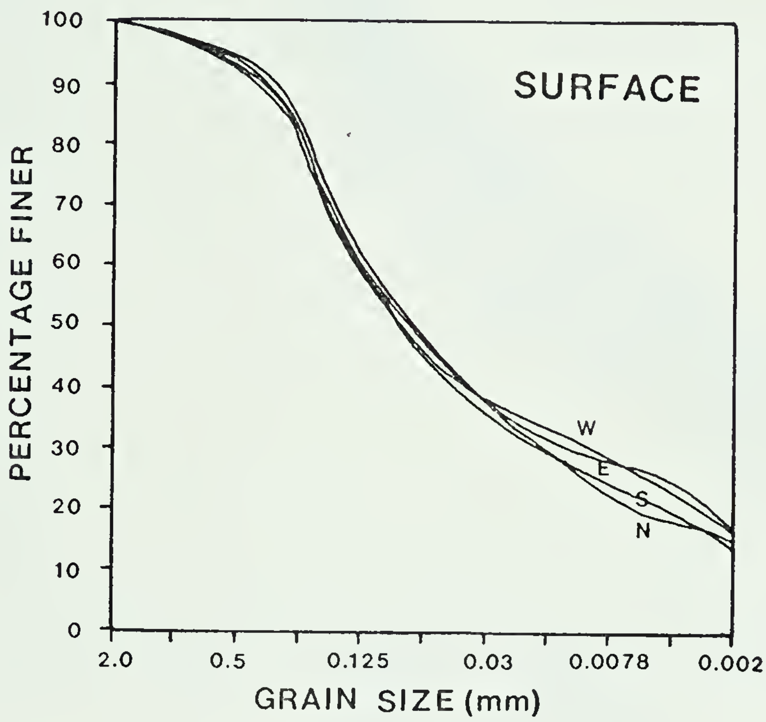
Graphs of cumulative grain size distribution are drawn for each of 34 surface soil samples, and curves are plotted for mean grain size distribution on each aspect for the top soil, soil at depth, and the calcareous layer at depth (FIG. 5-10).

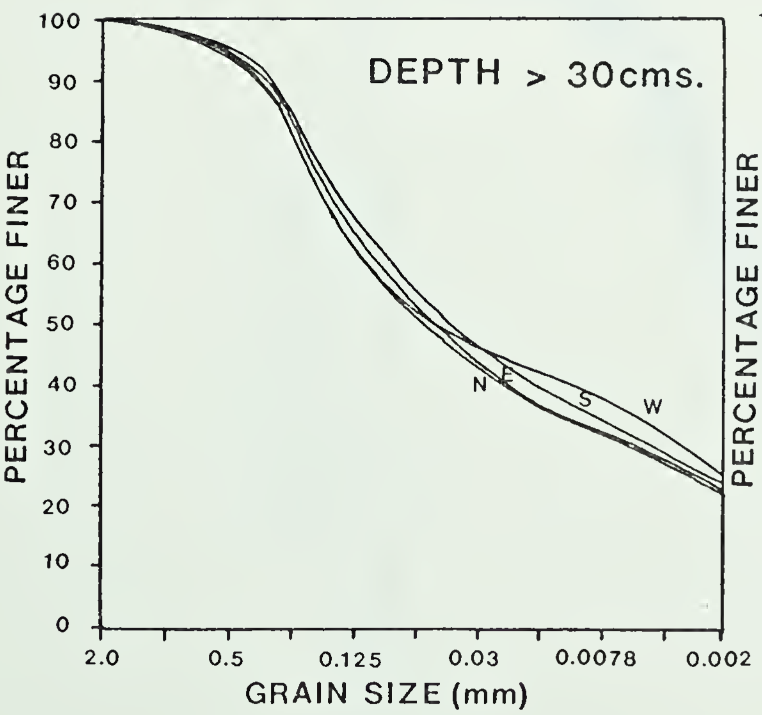
Median values from the topsoil samples (FIG. 5-11a) are concentrated in the fine sand to coarse silt range on all aspects. The widest range in median values is on northern slopes, from 0.12 mm to 0.03 mm while soils from east slopes, have narrow range from 0.07 mm to 0.05 mm. Direct comparison of possible differences on the four aspects is carried out by calculating a mean grain size distribution curve for each aspect (FIG. 5-10). Median values from these curves recorded in table V-18 reveal little difference between aspects. The curves of grain size distribution are very similar and median values determined from the curves fail to reveal any outstanding differences between different aspects.

FIGURE 5-10

# Mean Grain Size Curves

## -For each Aspect



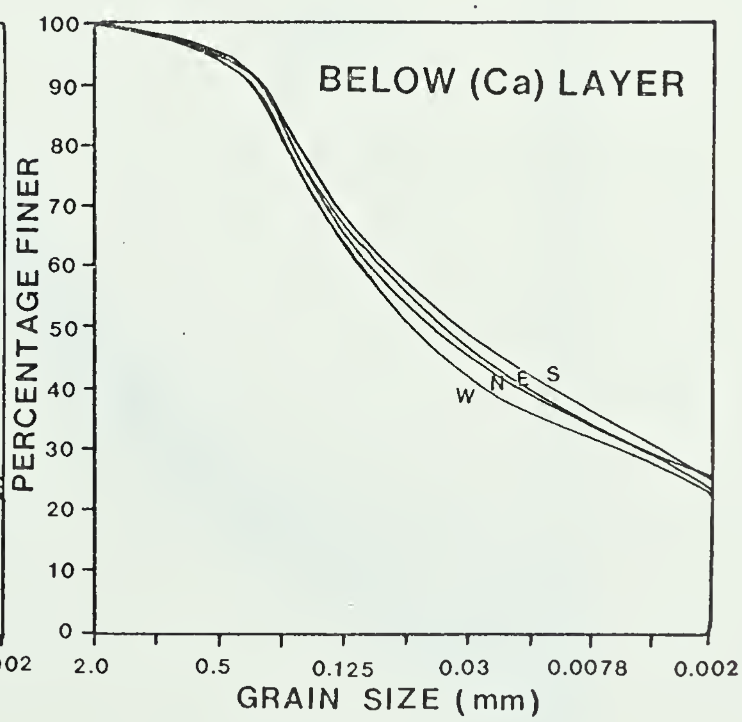



FIGURE 5-11 **Grain Size Curves -Surface Soil**

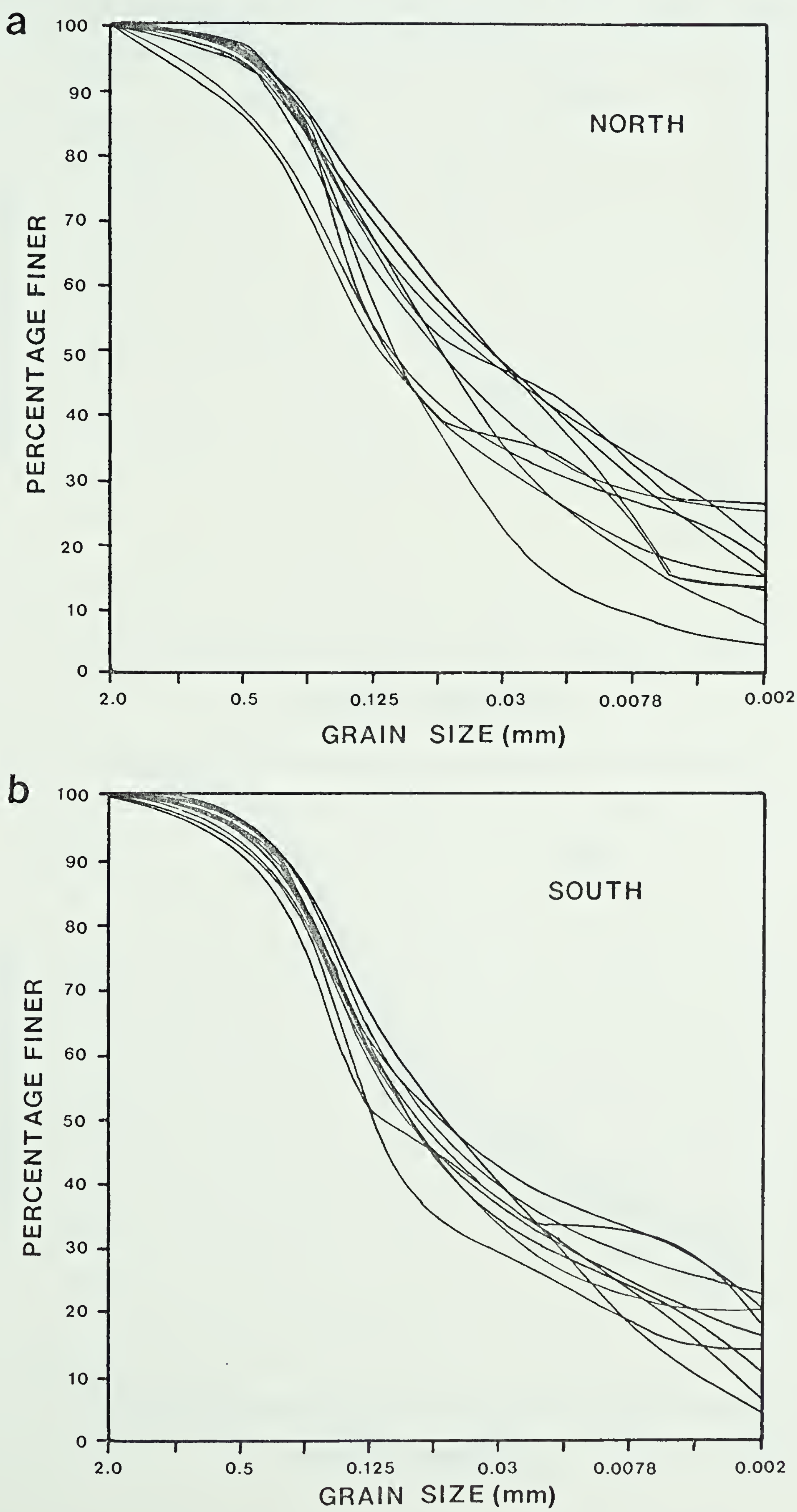
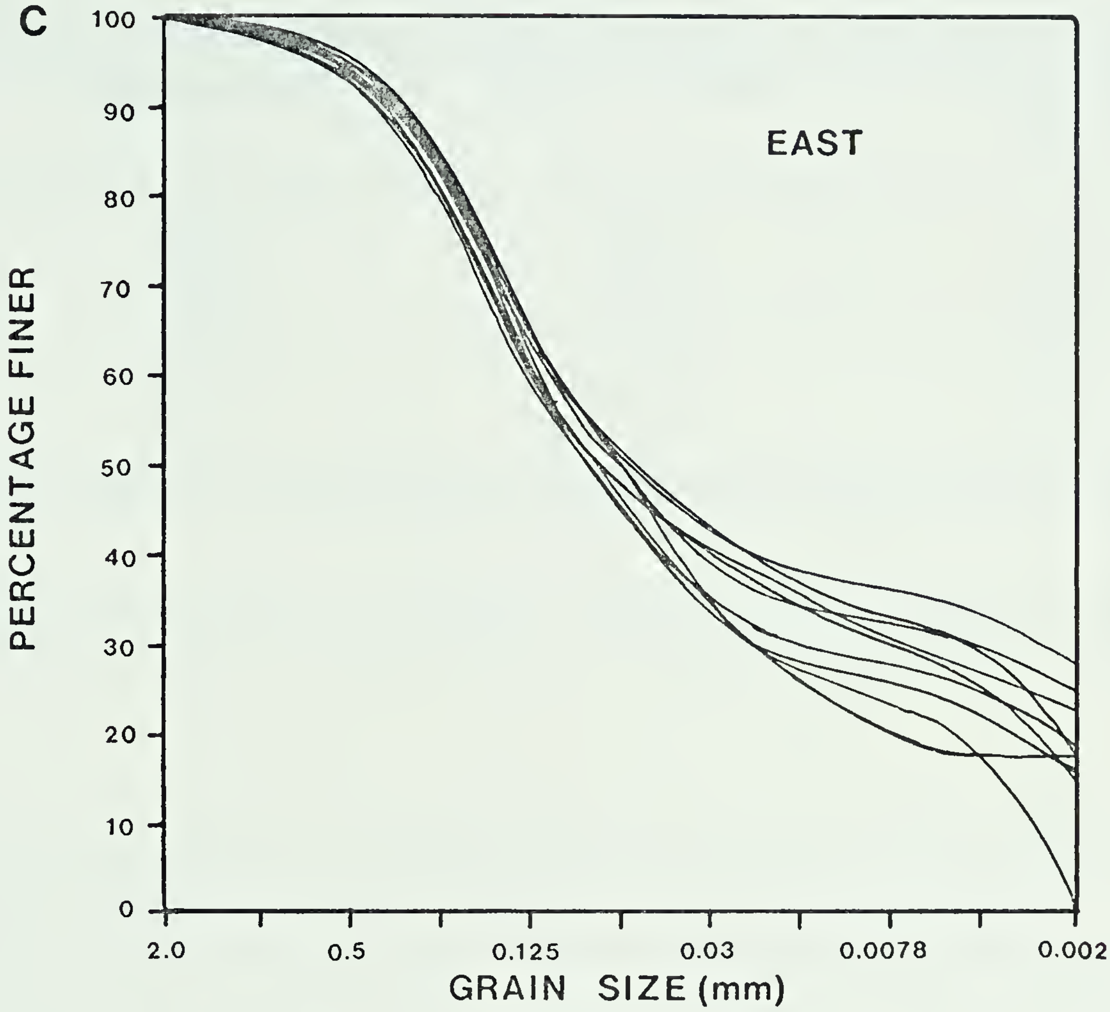


FIGURE 5-11 Grain Size Curves -Surface Soil

c




d

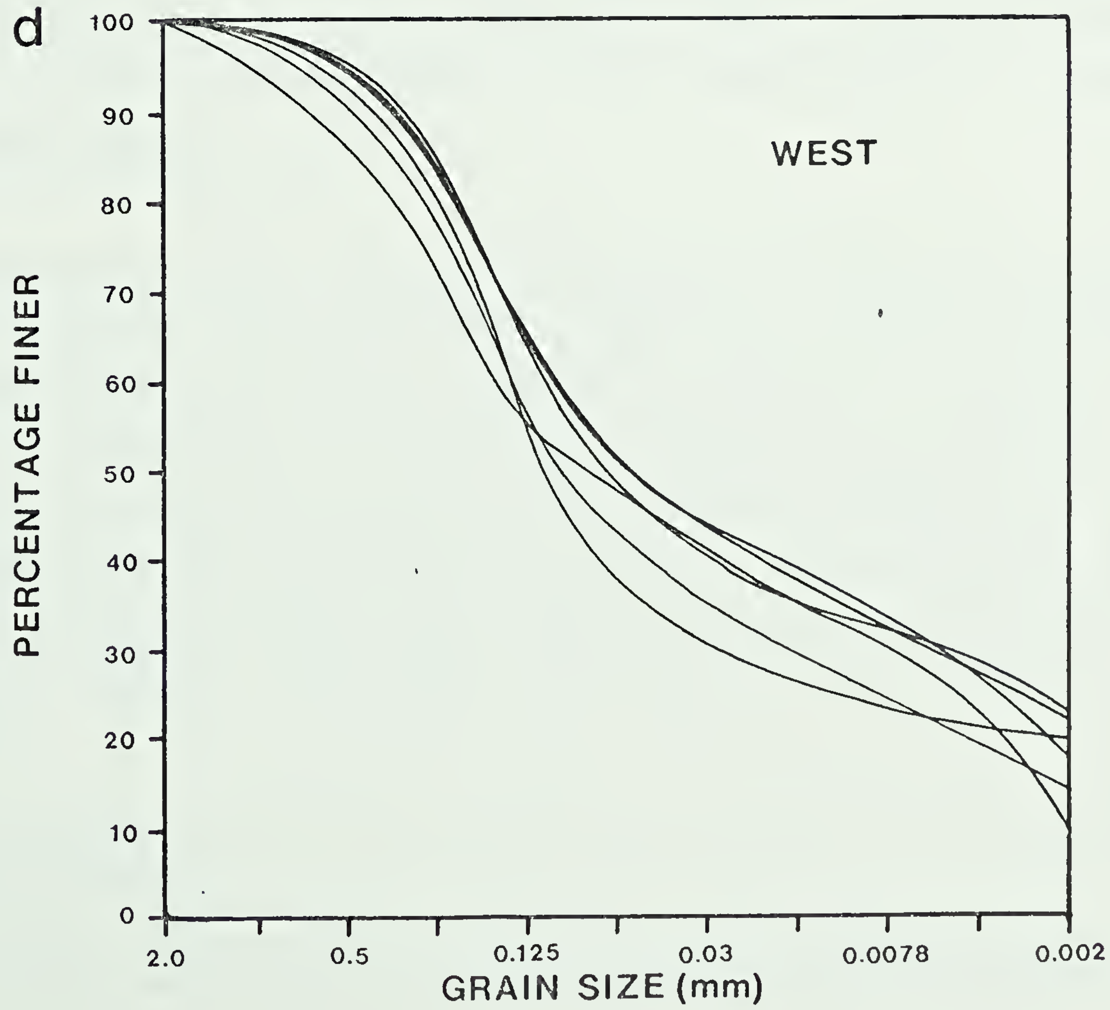


TABLE V-18. MEDIAN VALUES FROM MEAN GRAIN SIZE CURVES (mm)

| Aspect | Surface Soil | Soil at Depth | Calcareous Layer |
|---|---|---|---|
| North | 0.067 | 0.052 | 0.039 |
| South | 0.080 | 0.047 | 0.029 |
| East | 0.069 | 0.045 | 0.036 |
| West | 0.075 | 0.038 | 0.048 |

In every case values of skewness reveal a tail of fine material. Skewness values do not show any difference between samples from different aspects.

All evidence gained from examination of median values, U tests of difference in percentage sand content, as well as qualitative observation of the cumulative grain size curves indicates that grain size differences between aspects are not significant. Mean grain size curves for each aspect are almost identical. Median values and skewness values, as expected from observation of the curves, indicate no dominant trend between aspects.

The results of grain size analysis might have indicated major differences in grain size on different aspects as a result of different primary depositional processes. That this is not the case supports the assumption of similarity of depositional processes on each aspect. Furthermore, the effects of aspect, and the implied variation in microclimate, have been ineffective in producing any significant differences in range of grain sizes encountered with soil samples taken from the soil surface, or at depth, in the period since original deposition.

## 5.7. Carbon Content

Percentage weight loss of samples exposed to high temperature

gives a measure of carbon content. Organic matter can be determined by the use of an appropriate factor. However data from the organic carbon results are sufficient to give a relative measure of differences in organic content with change in aspect.

Thirty-four samples taken from the surface soil were subjected to analysis for carbon content. Table V-19, showing percentage weight of carbon according to aspect, reveals the mean carbon content for soils on north facing slopes is 8.20 per cent. The lowest mean value is for south facing slopes (5.60 per cent). Except for a slight tendency for west facing slopes to have a higher carbon content, south, east and west aspects show little difference in carbon content values.

U tests for differences of carbon content between aspects reveal no significant differences at the 95 per cent level (TABLE V-20). Yet the high soil moisture and low direct insolation on north facing slopes are optimum conditions for the accumulation of carbon and organic matter. It is possible that anomalous carbon content values for the north slope of mounds 3 and 19 may have had a considerable influence on the observed significance level for differences between north and south slope values.

## 5.8. Percentage Bare Ground

Mean values of bare ground on each aspect are calculated from the results in Table V-21 as 2.2 per cent on the north, 18.6 per cent south, 15.8 per cent east, and 3.9 per cent west. On individual mounds the pattern of this series rarely varies, bare ground is usually greatest in the series south > east > west > north. Between mounds there are some differences. Mound 13 east records the highest percentage 46.5 per cent (PLATE 5), and here there were indications of active soil movement on the surface. The data for mound 5 are worthy of particular note as only 4.5 per cent of the slope is recorded as bare on the south facing slope and only 3 per cent on the east. These data are of particular interest because of the peculiar infiltration rates already noted on mound 5.

TABLE V-19. PERCENTAGE CARBON CONTENT.

| Mound | North | South | East | West |
|---|---|---|---|---|
| 1 | 4.83 | 2.92 | 4.90 | - |
| 3 | 3.87 | 4.70 | 4.92 | - |
| 5 | 5.40 | 6.03 | 5.56 | - |
| 6 | 7.68 | 5.15 | 6.83 | 3.34 |
| 9 | 11.70 | 8.26 | 6.04 | - |
| 10 | 8.93 | 5.97 | 4.88 | 6.94 |
| 11 | 12.49 | - | 7.20 | 8.01 |
| 13 | 9.02 | 4.55 | 6.66 | 8.20 |
| 16 | 13.91 | 6.93 | - | 8.75 |
| 19 | 4.19 | 5.99 | 5.48 | 2.86 |
| MEAN | 8.20 | 5.60 | 5.83 | 6.61 |

TABLE V-20. RESULTS OF MANN-WHITNEY U TESTS FOR DIFFERENCES IN CARBON CONTENT WITH ASPECT.

| Hypotheses | $N_1$ | $N_2$ | U Table | Significance Level | Observed U value | Conclusion |
|---|---|---|---|---|---|---|
| Ho N = S<br>$H_1$ N > S | 9 | 10 | 8<br>24 | 0.001<br>0.05 | 28 | Accept Ho |
| Ho N = W<br>$H_1$ N > W | 6 | 10 | 3<br>14 | 0.001<br>0.05 | 19 | Accept Ho |
| Ho S = E<br>$H_1$ E > S | 9 | 9 | 7<br>21 | 0.001<br>0.05 | 35 | Accept Ho |
| Ho W = E<br>$H_1$ W > E | 6 | 9 | 2<br>12 | 0.001<br>0.05 | 19 | Accept Ho |

TABLE V-21. VEGETATION COVER - INDEX OF BARE GROUND (expressed as a percentage).

| Mound | North | South | East | West |
|---|---|---|---|---|
| 1 | 0.0 | 30.5 | 23.0 | - |
| 3 | 3.5 | 21.0 | 26.0 | - |
| 5 | 2.6 | 4.5 | 3.0 | - |
| 6 | 0.0 | 18.5 | 8.0 | 1.5 |
| 9 | 0.0 | 17.5 | 2.0 | - |
| 10 | 0.0 | 15.7 | 22.6 | 0.0 |
| 11 | 2.0 | - | 10.0 | 10.0 |
| 13 | 9.0 | 26.0 | 46.5 | 6.0 |
| 16 | 0.0 | 20.3 | - | 3.8 |
| 19 | 8.2 | 13.5 | 6.5 | 2.0 |
| MEAN | 2.2 | 18.6 | 16.4 | 3.9 |

TABLE V-22. RESULTS OF MANN-WHITNEY U TESTS FOR DIFFERENCES IN PERCENTAGE BARE GROUND WITH ASPECT.

| Hypotheses | $N_1$ | $N_2$ | U Table | Significance Level | Observed U Value | Conclusion |
|---|---|---|---|---|---|---|
| Ho N = S | | | | | | |
| $H_1$ S > N | 9 | 10 | 8 | 0.001 | 12 | Reject Ho |
| | | | 24 | 0.05 | | |
| Ho W = N | | | | | | |
| $H_1$ W > N | 6 | 10 | 3 | 0.001 | 21 | Accept Ho |
| | | | 14 | 0.05 | | |
| Ho E = W | | | | | | |
| $H_1$ E > W | 6 | 9 | 2 | 0.001 | 8 | Reject Ho |
| | | | 12 | 0.05 | | |
| Ho E = S | | | | | | |
| $H_1$ S > E | 9 | 9 | 7 | 0.001 | 33.5 | Accept Ho |
| | | | 21 | 0.05 | | |

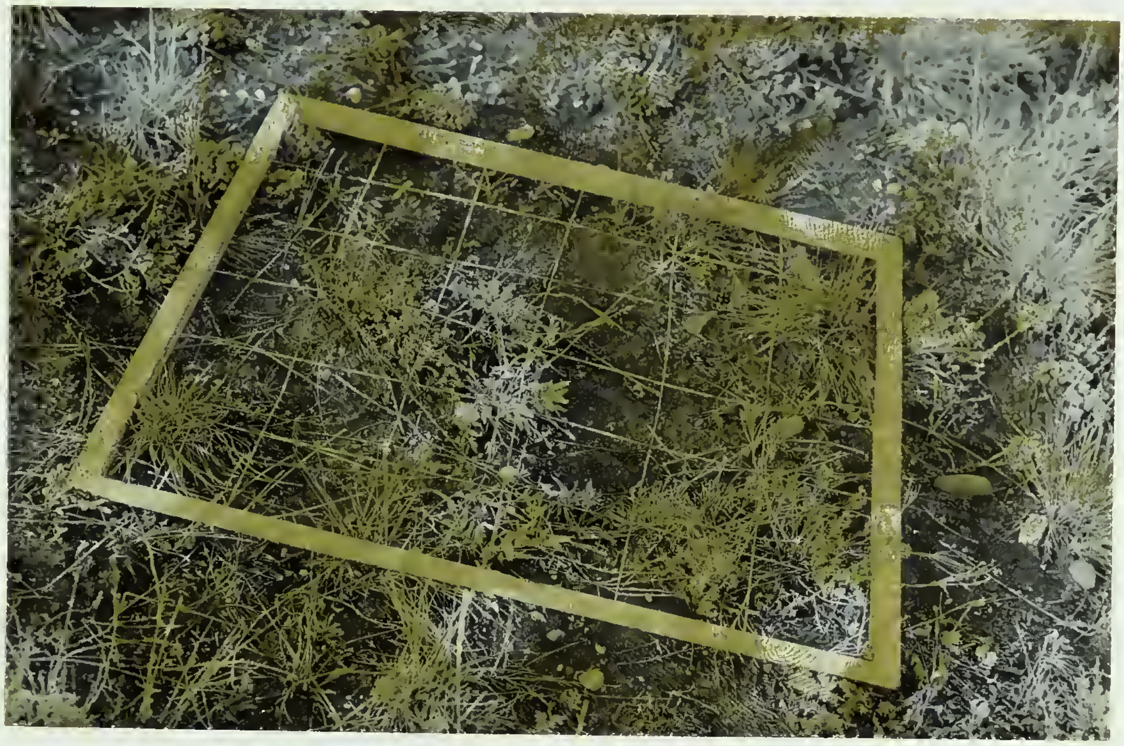


Plate 5: Ground cover conditions - Mound 13, east slope.
Photograph illustrates 46.5 per cent bare ground.

U test for significant differences in percentage bare ground between aspects illustrate the significance of the differences between north and south, east and west percentage values at the 95 per cent level. However, differences in values between north and west, and south and east percentage values are not significant (TABLE V-22). Vegetation cover is, therefore, significantly more dense on north and west facing slopes, than on slopes with south and east aspect.

## 5.9. Relative Mass-Wasting

### 5.9.1. Liquid Limit Tests

Samples for liquid limit testing were collected at a depth of 90 cm on three mounds. Analysis of the results was carried out to test for differences in potential flowage. Mounds 7, 8 and 9 were arbitrarily selected, and a total of 10 samples analysed. Results of the liquid limit tests are plotted in the form of 10 liquid limit flow curves (FIG. 5 -12). The moisture content at 25 blows in each case represents the content at which flowage will occur. Results for each aspect are given below (TABLE V-23).

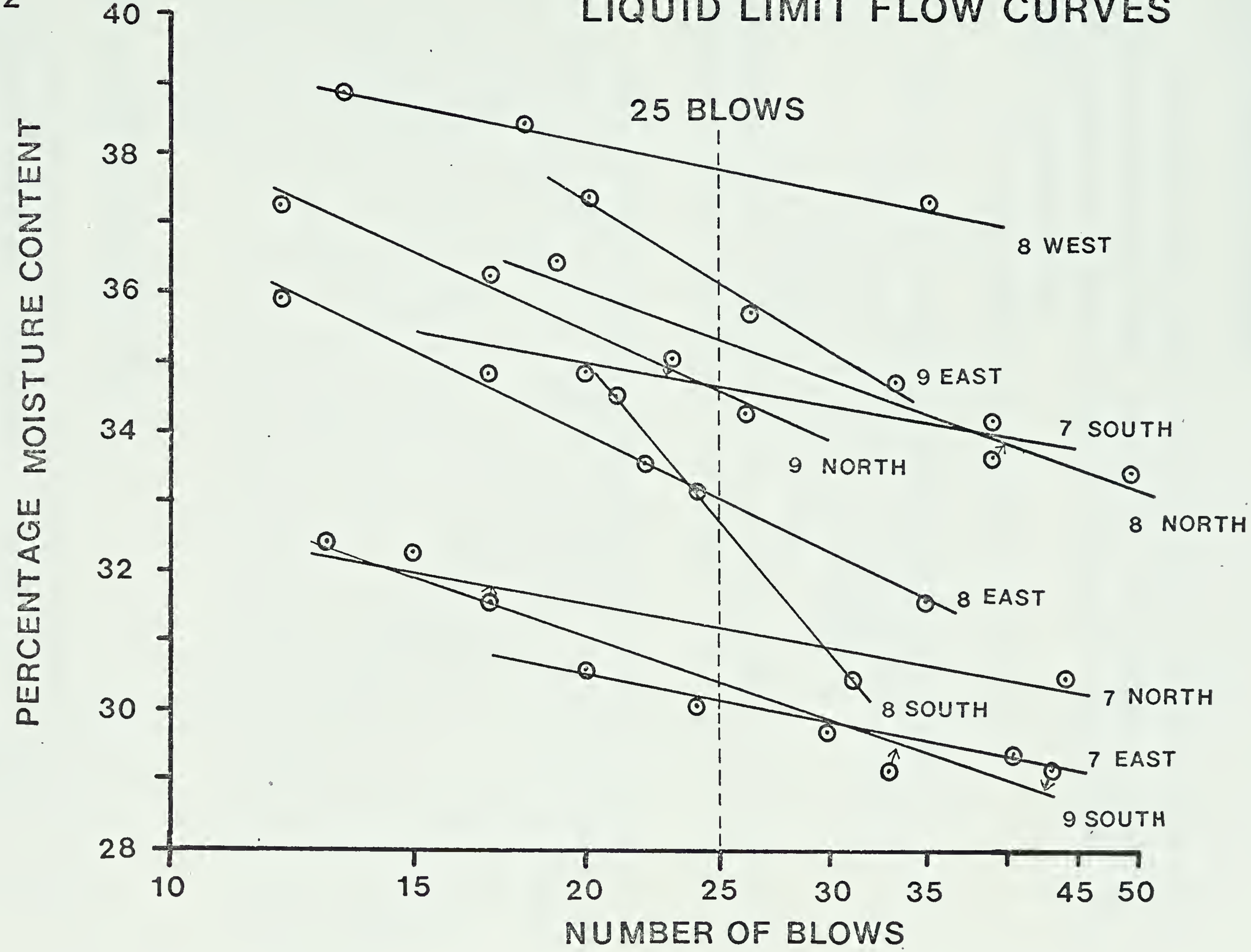
TABLE V-23. LIQUID LIMIT VALUES FOR MOUNDS 7, 8 AND 9.

| Mound | North | South | East | West |
|---|---|---|---|---|
| 7 | 31.30 | 34.61 | 30.20 | - |
| 8 | 35.30 | 32.82 | 33.10 | 37.84 |
| 9 | 34.73 | 30.52 | 36.20 | - |

The results of this pilot study reveal little evidence of differences in liquid limit between soils of different aspect. The range of values from this test is very low, only 7 per cent, and no particular aspect on the three selected mounds demonstrates consistently high, or low values. Tests using this method to determine possible differences in the ability of the slope materials to flow, or reflecting the possibility of the materials having flowed in the past, prove to be negative.

FIGURE 5-12

# LIQUID LIMIT FLOW CURVES



### 5.9.2. Microfabric Analysis

A chi-square ($\chi^2$) test is used to determine if the distributions of the two dimensional trends for the two rose diagrams in appendix D differ significantly from a uniform two dimensional distribution. Chi -square is determined by:

$$\chi^2 = \frac{(fo - fe)^2}{fe} \text{ for (N-1) degrees of freedom}$$

Where: fo = The number of observations per 10° sector.

fe = The expected number of observations per 10° sector in a uniform distribution.

N = The number of 10° sectors.

The computed result is compared with chi-square tables and the appropriate significance levels determined. A confidence limit was set at 5 per cent.

The microfabric sampled on the north slope records a value for chi-square of 23.88 with 17 degrees of freedom, and the microfabric from the south slope records a value for chi-square of 10.84 with 17 degrees of freedom. Both values are not significant at the 5 per cent level. It must be concluded that in both microfabrics there is no significant two dimensional trend. On the basis of two samples, it is not possible to suggest that the absence of significant orientation of the microfabric proves that soil creep or solifluction have not been active slope forming processes in this area. In order to make a definite statement concerning evidence of soil creep or solifluction more sampling at different depths is necessary.

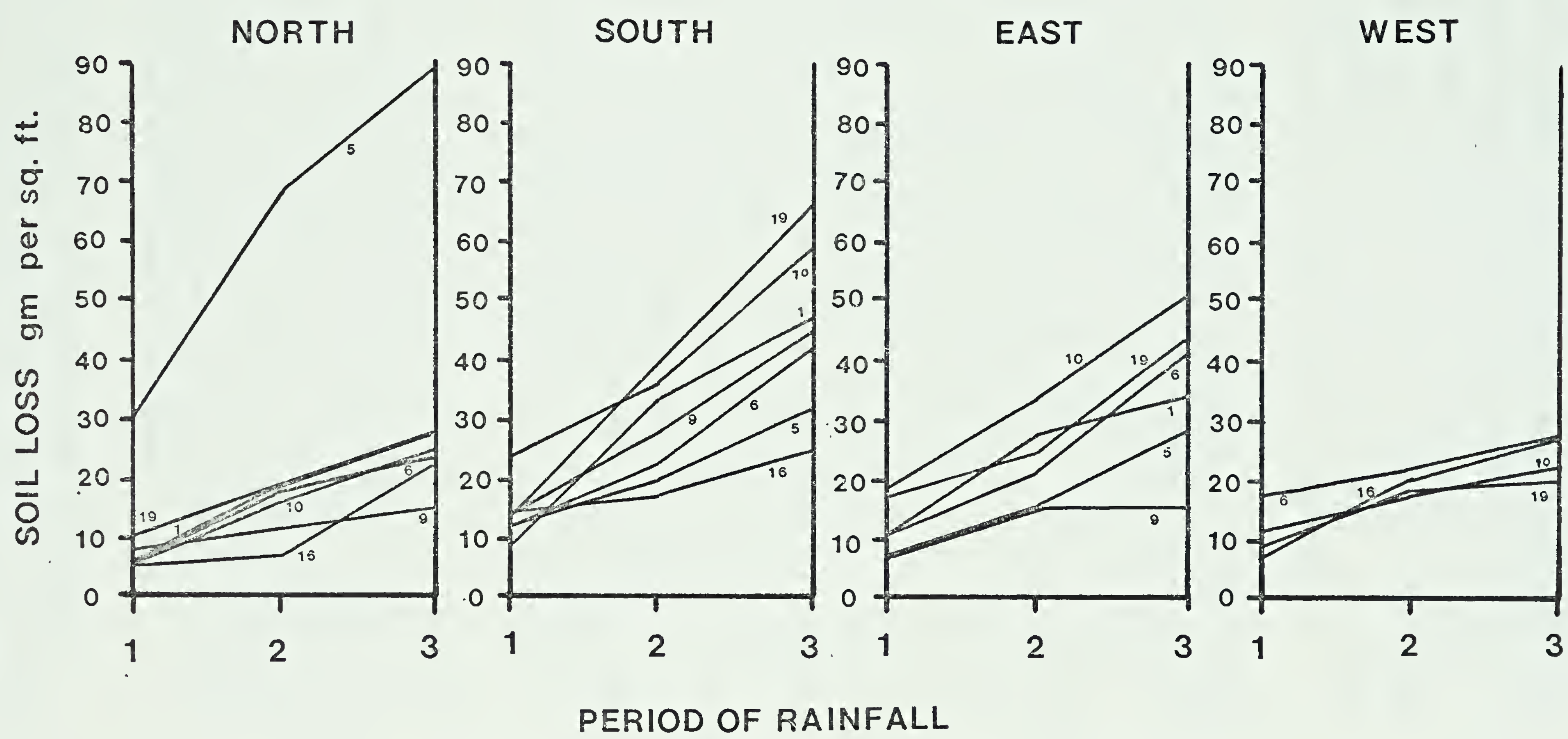
### 5.10. Rainfall Simulation Tests

The validity of the parameters chosen as indices of soil erodibility is tested by submitting twenty-four soil samples collected from seven mounds to periods of rainfall simulation in the laboratory.

Total soil losses for each of the three rainfall periods are presented in figure 5-13. Maximum soil loss from all samples occurs

FIGURE 5-13

## RAINFALL SIMULATION DATA



in the third period of rainfall. This suggests that maximum soil degradation takes place for these soils when the soil surface reaches saturation level. For the duration of the tests there was little evidence of surface crusting or sealing. Total soil loss in grams per square foot is small even on the 20° slope. Moderate soil losses testify to the strong resistance of the soils in the area. The high resistance probably results from the high degree of aggregation.

Results of soil losses under rainfall simulation for each aspect are relatively consistent. Material from north facing slopes with one exception record low soil losses. Mound 5 records excessive loss, thereby adding to the suspicion aroused using other field and laboratory techniques of the validity of the data from mound 5. If the result from mound 5 is disregarded the remaining soil loss records are lower for material from north facing slopes than losses incurred from material of south facing slope origins. With the exception of mound 1 in the first rainfall period, south facing slope material records higher losses. In the second and third periods six of the seven simulations on material from south facing slopes record higher soil losses than those from material taken from north facing slopes. Of six tests on material from east facing slopes, four record higher losses than the maximum soil loss on material from north facing slopes. Four rainfall simulation tests on material from west facing slopes demonstrate remarkably similar soil losses to those obtained from material taken from the north slopes.

The testing technique permits separation of soil loss by splash and by wash. Most tests reveal maximum loss is by splash, wash loss being sometimes less than 50 per cent of the splash loss. This pattern is consistent for the first two rainfall periods. In the third period six exceptions are found where wash loss exceeds the splash loss, and these exceptions are inclusive of material from all aspects, so loss through wash is not affected by differences of aspect.

The data confirms suspicions, aroused from data previously collected, that there is a distinct relationship between slope surface exposure and erodibility. Unfortunately the laboratory simulation

tests eliminate some actual field conditions, such as the effect of differences of vegetation cover, and differences in soil compaction, so that results obtained in the laboratory may not be very representative of field conditions.

# CHAPTER VI

## ANALYSIS OF FIELD AND LABORATORY RESULTS

### 6.1. Tests used in the Analysis

Interpretation of laboratory and field data is achieved by analysing the degree and direction of the correspondence between the variables. It is often possible to gain significant information from simple correlation analysis which may indicate a causal relationship between two variables. Consequently a simple correlation matrix has been developed for the variables in Table VI-1. Care in the interpretation of the simple correlation is necessary as mutual interdependence of sets of variables in a multivariate situation can effect the observed simple correlation. Some indication of the power of the other variables to affect the simple correlation coefficient is obtained by calculation of a series of partial correlations (TABLE VI-2).

Simple correlations are performed by determination of the Spearman rank correlation coefficient ($r_s$). This mode of analysis is used because the fact that variables are non-normally distributed necessitates the use of a ranked correlation test. Sets of observations for each variable are ranked from 1 to N in separate series and the value of $r_s$ computed by applying the formula:

$$r_s = 1 - \frac{6 \sum di^2}{N^3 - N}$$

Where: $\sum di^2$ = The sum of the squared variations between ranked values.

N = Number of observations for each series.

To determine if the observed value of $r_s$ differs significantly from zero, a t-test is used. Computations of the value, t, are made according to the formula:

$$t = r_s \sqrt{\frac{N - 2}{1 - r_s^2}}$$

The value of t is distributed as the student t distribution with (N-2) degrees of freedom.

TABLE V1-1 MATRIX OF $r_s$ VALUES SIGNIFICANTLY DIFFERENT FROM ZERO AT 95 PER CENT LEVEL.

| | $X_1$ | $X_2$ | $X_3$ | $X_4$ | $X_5$ | $X_6$ | $X_7$ | $X_8$ | $X_9$ |
|---|---|---|---|---|---|---|---|---|---|
| $X_1$ | 1.0 | -0.4408 | 0.6988 | 0.3728 | 0.5245 | | -0.4398 | | -0.3547 |
| $X_2$ | | 1.0 | -0.6042 | | -0.3962 | | 0.5015 | | |
| $X_3$ | | | 1.0 | | 0.3667 | | -0.6237 | | |
| $X_4$ | | | | 1.0 | -0.4472 | -0.4660 | 0.5315 | | |
| $X_5$ | | | | | 1.0 | | | | -0.4628 |
| $X_6$ | | | | | | 1.0 | | | |
| $X_7$ | | | | | | | 1.0 | | |
| $X_8$ | | | | | | | | 1.0 | |
| $X_9$ | | | | | | | | | 1.0 |

TABLE V1-2 MATRIX OF ALL PARTIAL CORRELATION COEFFICIENTS

| | $X_1$ | $X_2$ | $X_3$ | $X_4$ | $X_5$ | $X_6$ | $X_7$ | $X_8$ | $X_9$ |
|---|---|---|---|---|---|---|---|---|---|
| $X_1$ | 1.0 | -0.0524 | $0.4867^{+}$ | -0.1866 | $0.2912^{\circ}$ | -0.0545 | 0.1259 | 0.2177 | -0.0283 |
| $X_2$ | | 1.0 | -0.2440 | -0.0654 | $-0.3438^{+}$ | 0.1422 | 0.1789 | -0.1657 | -0.0352 |
| $X_3$ | | | 1.0 | $0.2685^{\circ}$ | -0.1859 | 0.1334 | $-0.5359^{*}$ | $-0.3753^{+}$ | $-0.3012^{\circ}$ |
| $X_4$ | | | | 1.0 | -0.2066 | $-0.4856^{+}$ | $0.5735^{*}$ | 0.0261 | 0.2590 |
| $X_5$ | | | | | 1.0 | -0.0993 | 0.0912 | -0.1763 | $-0.3474^{+}$ |
| $X_6$ | | | | | | 1.0 | 0.2560 | 0.2188 | -0.0751 |
| $X_7$ | | | | | | | 1.0 | -0.1222 | $-0.2869^{\circ}$ |
| $X_8$ | | | | | | | | 1.0 | -0.0471 |
| $X_9$ | | | | | | | | | 1.0 |

$X_1$ - Mean Slope Angle
$X_2$ - Infiltration Rate
$X_3$ - Per Cent Bare Ground
$X_4$ - Soil Moisture Content
$X_5$ - Soil Strength
$X_6$ - Per Cent Sand Content
$X_7$ - W.S.A. > 0.5 mm.
$X_8$ - Soil Depth
$X_9$ - Organic Content

Significance Levels:

$*$ 99.5 per cent
$+$ 95.0 per cent
$\circ$ 90.0 per cent

A partial correlation can clarify the relationship between sets of variables by controlling the other variables which may have influenced the observed simple correlation. Partial correlation involves taking the difference between the actual value of the independent variable and its value as predicted by the control variables. The same procedure is then carried out for the dependent variable. The simple correlation between these adjusted variables is the partial correlation. The computer program used is based on the formula:

$$r_{ij.k} = \frac{r_{ij} - (r_{ik})(r_{jk})}{\sqrt{1 - r_{ik}^2}\ \sqrt{1 - r_{jk}^2}}$$

Where: k is the control variable
i is the independent variable
j is the dependent variable

## 6.2. Analysis of the Linkages between the Major Variables

### 6.2.1. Data Presentation

Results of the simple correlation tests are displayed in the form of a simple correlation matrix in table VI-1. The cut-off point for acceptable levels of significance is 97.5 per cent, as a lower level of significance does not improve the system of linkages already established. Linkages between the selected variables are displayed in the form of a simple model in figure 6-1. Partial correlation data are treated in a similar fashion, with results presented in the form of a correlation matrix in table VI-2. Linkages between the variables, revealed by partial correlation, are displayed in figure 6-2.

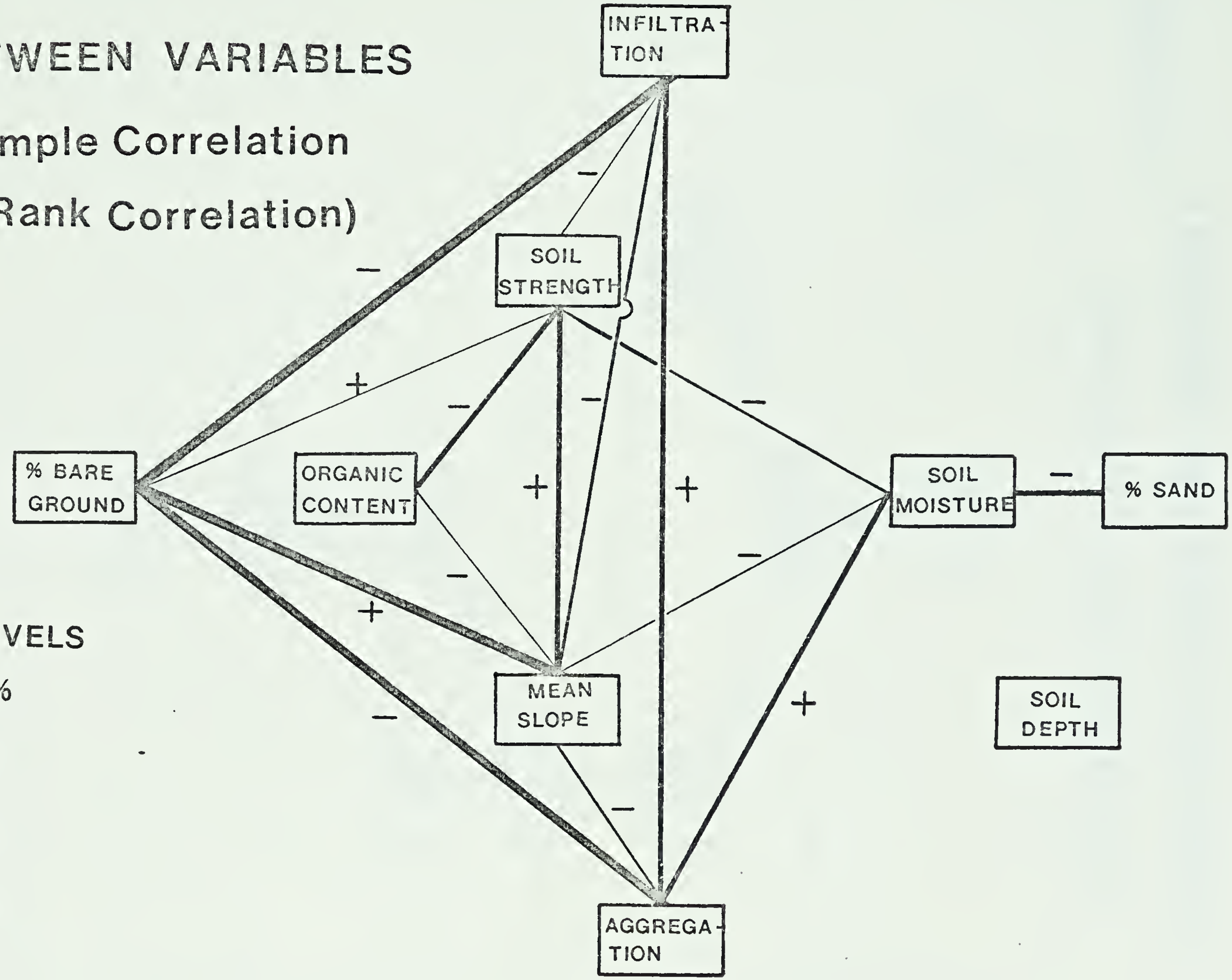
### 6.2.2. Infiltration Rate

Simple correlation reveals that infiltration is highly related to four of the chosen variables. A strong negative relationship with percentage bare ground is of particular interest as most studies of infiltration rates have a prerequisite that vegetation is removed before testing. This is true for laboratory studies, where vegetation is ignored, and some field studies (Verma and Toogood 1968). Musgrave and Free (1936)

FIGURE 6-1

# LINKAGES BETWEEN VARIABLES

## Result of Simple Correlation
## (Spearman Rank Correlation)



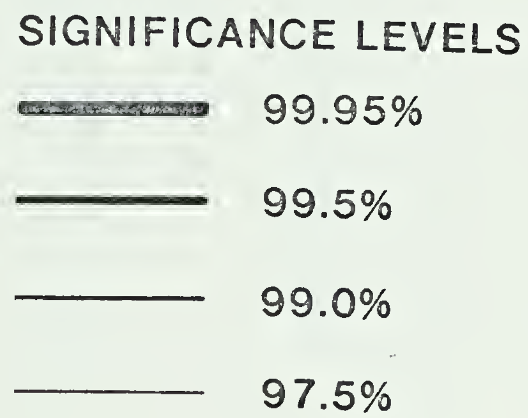
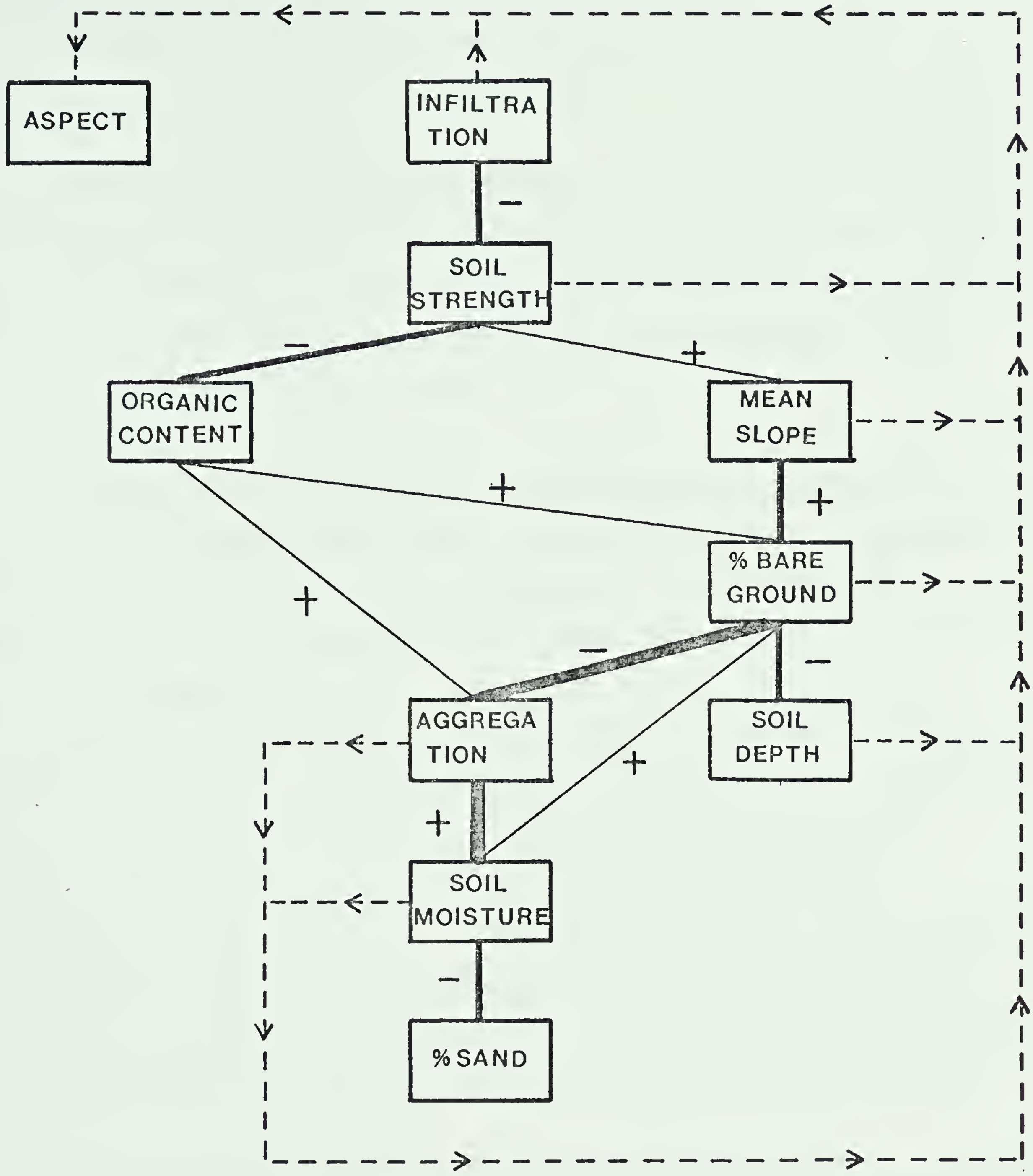



FIGURE 6-2

# LINKAGES BETWEEN VARIABLES

## Results of Partial Correlation




Significent Variation with Aspect 95% level

Significant Correlation 99.5% level

Significant Correlation 95% level

Significant Correlation 90.0% level

found that close vegetation increased infiltration sufficiently to account for the marked control of surface runoff. Plot experiments showed that infiltration on vegetated ground was 50 per cent higher than on ground without vegetation. The present study supports the views expressed by Musgrave and Free that vegetation may considerably influence infiltration.

Simple correlation of infiltration rate and aggregation produced a correlation coefficient of +0.5015. This value, which is higher than the coefficient of 0.3 obtained by Free et al (1940), supports the conclusion of Lutz (1934) that high percentages of large sized aggregates are responsible for high infiltration rates.

The results of partial correlation may be used to question the validity of a causal relationship being responsible for the significant simple correlation coefficients discussed above. Initial simple correlations between infiltration and percentage bare ground, and between infiltration and aggregation are not supported by the lower partial correlation coefficients, produced by controlling the effects of the other variables. Although simple techniques show an insignificant correlation between soil strength and infiltration rates, partial correlation clarifies the relationship, establishing a negative correlation significant at the 95 per cent level. The suggestion that soil strength or compaction may be the controlling factor influencing infiltration is supported by the conclusions of Musgrave and Free (1936) and corresponds closely with the correlation of 0.36 determined by Free et al (1940).

In contrast with the conclusion of Philip (1957) and Tisdall(1951), that soil moisture was of prime importance affecting infiltration in soils, soil moisture content is found not to have a significant correlation with infiltration rates. Baver (1956 p. 451) records Wollney's comment that:

> ... runoff was greater on different exposures according to the following series, north > west > east > south. The moisture content of the soil increased in the same order.

Results from the present study suggest that there are other factors of more importance to infiltration than soil moisture content.

### 6.2.3. Aggregation

Simple correlation reveals that aggregation is significantly related to four variables. The simple correlation of aggregation with percentage bare ground is $r_{73} = -0.6237$. The partial correlation coefficient is lower, $r_{73.1245689} = -0.5359$. Both coefficients show a highly significant inverse relationship between aggregation and percentage bare ground. A positive partial correlation between organic content and aggregation is at a low level of significance, while simple correlation between organic content and aggregation reveals no significant relationship. The partial coefficient supports the work of Baver (1935 and 1956) and Robinson and Page (1950). Baver noted organic matter was of greater importance to aggregation if the soil contained less than 25 per cent clay, most samples in this study fall within that category.

Simple correlation of aggregation and mean slope angle produces a correlation coefficient of -0.4398 which is significant at the 99 per cent level. Partial correlation between aggregation and mean slope angle produces a much lower correlation coefficient of +0.1259. Interrelationships between soil aggregation and mean slope and the other variables have been effective in producing the high simple correlation significance. The similarity of the correlation coefficients, 0.5135 and 0.5735 for simple and partial correlation respectively, illustrates that soil moisture is directly related to aggregation, and that this relationship is little affected by other variables. The results of this study suggest aggregation is significantly related to three of the chosen variables, vegetation cover, organic content, and soil moisture.

### 6.2.4. Soil Strength

Simple correlation shows soil moisture is related to soil strength, $r_{54} = -0.4472$. Other variables may have influenced this result as the

partial correlation is no longer significant, $r_{54.1236789} = -0.2066$. Chorley (1959) found that soil moisture was not necessarily the most important influence on soil strength if the soil had a high sand content. Shaw et al (1942) and Baver (1956) noted that the effects of moisture content on soil strength became especially important as the percentage of clay increased.

Organic content is negatively correlated with soil strength in both correlation tests. Inclusion of the other variables reduces the coefficient, but the value remains significant at the 95 per cent level. The three significant correlations under the partial correlation (TABLE VI-2) are organic content, mean slope angle, and infiltration, though infiltration is probably the effect rather than the cause of compaction.

## 6.3. The Influence of Aspect on the Response of the Variables

Aspect is not included in the simple or partial correlation tests, so the results of U tests for differences of each of the chosen variables with aspect computed in Chapter V, are used to ascertain which slope is relatively more susceptible to erosion, or reflects distinct differences in microclimate. Susceptibility to erosion is based on the results of infiltration measurements, which when combined with rainfall intensity data can indicate the possibility of the occurrence of runoff. Aggregation, soil strength and grain size distribution results reflect the resistance of the soil to slope wash and soil flowage in suspension. Results from Chapter V suggest a basic reaction to microclimate variation as reflected by aspect is ascertainable between aspect and soil moisture content, percentage bare ground, and soil depth. Values of organic content show a near significant difference between north and south slopes.

Differences in exposure to direct insolation, as noted by Sellers (1965) and Geiger (1966), result in two extremes of microclimate. North slopes receive least direct insolation and south slopes receive

maximum exposure to direct insolation. In southern Alberta sunshine hours are usually higher than hours of cloudiness, so in this area direct insolation is dominant. North slopes in this area demonstrate greater soil depth, moisture content, and vegetation cover than south slopes, significant at the 95 per cent level. Mean values for organic content show a near significant response, with north slopes recording higher values. Microclimate differences are not as pronounced between east and west slopes (TABLE VI-3a). This reflects to some extent the lack of any marked difference in the amount of direct insolation received on these aspects (Geiger 1966).

TABLE VI-3. SIGNIFICANCE OF DIFFERENCES BETWEEN SELECTED ASPECTS FOR EACH VARIABLE.

| Variable | Result of U tests at the 0.05 level. | | | |
|---|---|---|---|---|
| A. Basic differences in microclimate | | | | |
| Carbon content | N = S | N = W | S = E | W = E |
| Moisture content | N > S | N = W | S = E | W = E |
| Vegetation cover | N > S | N = W | E > S | W > E |
| Soil depth | N > S | N = W | S > E | W > E |
| B. Reflection of differences in erodibility | | | | |
| Soil strength | S > N | W > N | S > E | E > W |
| Aggregate stability | N > S | N = W | E = S | W > E |
| Grain size | N = S | N = W | E = S | W = E |
| Infiltration | N > S | N = W | S = E | W = E |

> Indicates significantly greater at 0.05 level.

= Indicates any variation is due to chance.

The results obtained for the remaining variables, soil strength, infiltration rates, soil aggregate stability, and grain size, recorded

in Chapter V, can be used as indices of erodibility. Analysis for differences of grain size distribution with aspect shows no significant differences, so grain size is rejected as a useful index of erodibility in this area. The three remaining indices are found to vary significantly with aspect at the 95 per cent level (TABLE VI-3b). Slopes receiving minimum direct insolation, (north slopes), have significantly higher infiltration rates and lower soil strength. From the previous analysis, (6.2.2.), it is known that these two variables are negatively related as revealed by simple correlation. Thus surface compaction may be an important factor affecting infiltration. Higher aggregate stability is characteristic of north facing slopes. Therefore, north facing slopes, less exposed to direct insolation, exhibit high infiltration, high aggregate stability, and maximum vegetation cover. The result is greater stability of the slope material on that aspect.

Differences in susceptibility to erosion between slope materials of east and west slopes are not as distinct as between north and south slopes. Aggregation is significantly higher on west slopes, suggesting greater ability to resist removal of soil by slope wash, but the probability of runoff due to lower infiltration rates is not significantly greater.

North slopes demonstrate maximum ability to resist surface runoff and consequent surface soil loss by slope wash. The high infiltration capabilities of north facing slopes make these slopes capable of absorbing the heavy rainfall characteristic of the storms of this area. In the event of runoff through excessive precipitation, the possibility of resultant soil removal is much reduced due to the relatively high aggregation encountered on north slopes. West slopes are relatively more stable than south and east slopes. East and especially south slopes have a greater susceptibility to surface runoff and resultant soil loss because of low infiltration rates and low aggregation. Soils on south and east slopes are comparitively easily removed by runoff which, as the infiltration data shows, is more likely to occur on these slopes.

## 6.4. The Influence of mean slope Angle on the Response of the Variables

It seems apparent from the previous analysis that aspect is the controlling variable affecting surface soil erodibility in this area. Seven of the total of nine variables are found to vary significantly with aspect at the 95 per cent level (Chapter V). Grain size and organic content do not show a significant relationship with aspect. Mean slope angle is significantly correlated with six of the eight variables in the simple correlation (FIG. 6-1). Soil depth and grain size fail to correlate significantly with mean slope angle. Results from Chapter IV show that aspect and mean slope angle are significantly related. Some assessment is necessary of the role of mean slope angle and its relative importance compared with aspect in affecting the response of the variables on different slopes.

A certain affinity of the variable response is suggested between slopes of north and west aspect, as opposed to slopes of south and east aspect. Soil strength is the only variable demonstrating significant differences between slopes of north and west aspect, and difference in values between south and east slopes is only significant for soil strength, soil depth and vegetation cover. The trend of these results can be seen to be related to the trend of mean slope values on each aspect. North and west slopes are more gentle, and south and east slopes relatively steep. The observation suggests mean slope angle may be an important factor influencing the response of the other variables.

To further test the importance of mean slope angle and its influence on the other variables, correlation between mean slope angle values and values obtained for the other variables are computed while aspect is held constant. The $r_s$ values are computed using the Spearman rank correlation (6.1.). Correlation coefficients and significance values are presented in table VI-4. Mean slope angle values have a maximum range on north slopes. Correlation coefficients for north slopes are extremely low and none are significant at the 99 per cent level. One variable, soil depth, has a significant relationship with mean slope angle at the 95 per cent

TABLE VI-4. RESULTS OF CORRELATIONS WITH MEAN SLOPE ANGLE WHEN ASPECT IS HELD CONSTANT.

| Parameter | N | Acceptable $r_s$ Value at 0.05 level | $r_s$ | Significant at 0.05 level |
|---|---|---|---|---|
| North Slopes | | | | |
| $X_2$ Infiltration rate | 9 | 0.600 | -0.382 | No |
| $X_3$ % Bare ground | 10 | 0.564 | -0.127 | No |
| $X_4$ Moisture content | 10 | 0.564 | -0.078 | No |
| $X_5$ Soil strength | 20 | 0.377 | +0.085 | No |
| $X_6$ % Sand content | 10 | 0.564 | +0.248 | No |
| $X_7$ Aggegation | 20 | 0.377 | +0.300 | No |
| $X_8$ Soil depth | 20 | 0.377 | +0.397 | Yes |
| $X_9$ Carbon content | 10 | 0.564 | -0.090 | No |
| South Slopes | | | | |
| $X_2$ Infiltration rate | 8 | 0.643 | -0.190 | No |
| $X_3$ % Bare ground | 9 | 0.600 | -0.344 | No |
| $X_4$ Moisture content | 9 | 0.600 | +0.016 | No |
| $X_5$ Soil strength | 18 | 0.399 | -0.065 | No |
| $X_6$ % Sand content | 9 | 0.600 | -0.600 | Yes |
| $X_7$ Aggegation | 18 | 0.399 | +0.071 | No |
| $X_8$ Soil depth | 18 | 0.399 | +0.344 | No |
| $X_9$ Carbon content | 9 | 0.600 | +0.016 | No |
| East Slopes | | | | |
| $X_2$ Infiltration rate | 8 | 0.643 | +0.095 | No |
| $X_3$ % Bare ground | 9 | 0.600 | +0.400 | No |
| $X_4$ Moisture content | 9 | 0.600 | +0.533 | No |
| $X_5$ Soil strength | 17 | 0.413 | -0.442 | Yes |
| $X_6$ % Sand content | 9 | 0.600 | +0.100 | No |
| $X_7$ Aggegation | 17 | 0.413 | -0.333 | No |
| $X_8$ Soil depth | 17 | 0.413 | -0.024 | No |
| $X_9$ Carbon content | 9 | 0.600 | -0.050 | No |

<u>West Slopes</u>

| | | | | |
|---|---|---|---|---|
| $X_2$ Infiltration rate | 6 | 0.829 | +0.829 | Yes |
| $X_3$ % Bare ground | 6 | 0.829 | -0.771 | No |
| $X_4$ Moisture content | 6 | 0.829 | +0.028 | No |
| $X_5$ Soil strength | 15 | 0.437 | -0.157 | No |
| $X_6$ % Sand content | 6 | 0.829 | +0.542 | No |
| $X_7$ Aggegation | 15 | 0.437 | +0.143 | No |
| $X_8$ Soil depth | 15 | 0.437 | +0.269 | No |
| $X_9$ Carbon content | 6 | 0.829 | 0.000 | No |

level. On south slopes a correlation between mean slope angle and percentage sand content is significant at the 95 per cent level. East slopes show a significant correlation between mean slope angle and soil strength, and west slopes between mean slope angle and percentage bare ground. From a total of thirty-two $r_s$ values only four are significantly correlated with changes in mean slope angle at the 95 per cent level, and none are significantly correlated at the 99 per cent level. Predominantly low correlations, and fluctuation in the direction of correlation between different aspects suggests that mean slope angle is very much subordinate to the influence of aspect in influencing the response of the chosen variables in this area.

Some qualitative assessment of the importance of mean slope angle can be made. Results from Chapter V of the U tests for differences between the values obtained for each variable with differences in slope aspect show that west slopes differ significantly from east slopes in vegetation cover, soil depth, aggregation and soil strength. From what is known of microclimatic variation and aspect (Geiger 1966), a similar response on these two aspects would have been expected. That this is not the case on these aspects, where the effects of aspect and its implied influence on microclimate are similar, may reflect the influence of mean slope angle. The difference is particularly noticeable in the field, especially in terms of vegetation cover.

# CHAPTER VII

# CONCLUSIONS

The analysis of slope profiles (Chapter IV) reveals that for mean slope angle values of the zone of maximum declivity, south and east slopes are significantly steeper than north and west facing slopes. Therefore differences of slope angle with aspect do exist.

In order to test the relationship between erosion susceptibility and aspect, analysis for significant differences between selected variables, with aspect, has been carried out. The following eight variables were measured in the field and laboratory; soil strength, infiltration rate, aggregation, organic content, moisture content, grain size distribution, soil depth, and vegetation cover. U tests between variables on different aspects reveal there are significant differences, with aspect, for six of the variables (Chapter V). The exceptions are grain size distribution and organic content. The absence of significant differences in each of the eight variables with changes in mean slope angle, with aspect held constant (Chapter 6.5), shows that mean slope angle does not exert a significant influence on the variables. Given the fact that significant differences do occur with aspect, and they are not related to changes in slope angle, it may be concluded that the significant external influences which vary with aspect are microclimatic.

The influence of each of the selected variables on erodibility is made before assessing the relative erodibility on slopes of different aspects. The simple relationship between precipitation, infiltration, and runoff means that high infiltration rates reduce runoff, and consequent slope wash, in a given area. Highest rainfall intensities in prairie storms usually occur at the commencement of the storm (Verma 1968), when the soil surface is most capable of absorbing rainfall. If the high intensity rainfall occurs while the soil is saturated, runoff is inevitable. Infiltration rate is highly correlated with vegetation cover

(FIG. 6-1). This is of particular interest as the unusually dense vegetation cover observed on the south slope of mound 5 may explain the anomalously high infiltration rate encountered on that slope. In most laboratory studies and some field studies of infiltration rates, vegetation as a factor influencing infiltration has been ignored. The high partial correlation obtained from the relationship between infiltration rate and soil compaction is similar to that obtained by Musgrave and Free (1946). The suggestion that the surface of the soil is of extreme importance to infiltration is therefore supported, and the precautions taken in the insertion of the infiltration apparatus are justified.

High aggregate stability and differences in grain size distribution can enhance resistance to erosion in the event of runoff, making the soil surface less susceptible to erosion by slope wash. Aggregation is found to have a direct relationship with vegetation cover, soil moisture, and organic content (FIG. 6-1).

Mass-wasting by soil flowage, or soil creep, is strongly influenced by the soil moisture content and soil strength (Kirkby 1967, p. 376). Soil moisture content and soil strength show a negative correlation which is significant at the 99 per cent level. However, the correlation between soil moisture and soil strength is not as strong as that suggested to the author by Professor Toogood (personal communication June 1971). Partial correlation reveals a significant relationship between soil strength and organic content, mean slope angle and infiltration rate.

The importance of vegetation, in promoting slope stability, has been emphasised by Putnam and Sharp (1940), Walker (1948), and Melton (1960). The suggestion is that a dense vegetation cover can prevent excessive erosion as a result of close binding root systems, and by protecting the soil surface from direct rainfall impact. Thus dense vegetation can maintain steeper slope angles.

Based on what has been said concerning the possible influence of the chosen variables on erodibility, an assessment of the relative

erodibility of slopes of different aspects is made (Chapter V). Comparison of rainfall intensity with infiltration rates, using either clear or turbid water scales, shows that the possibility of runoff in this area is slight. Because north facing slopes maintain high infiltration rates this promotes high resistance to erosion on these slopes. Runoff is more probable on south and east slopes, where an intensity of 3.5 cm per hour will exceed infiltration capacity. An intensity of 5 cm per hour is required to produce runoff on north and west slopes. Soil samples from north and west slopes have significantly higher aggregate stability, and are therefore less liable to removal by slope processes than material from other aspects. South and to a lesser extent east slopes are therefore most susceptable to erosion, due to the combination of low infiltration rates and the fact that the slope material is less stable in terms of aggregate stability. Grain size distribution is found not to differ significantly between aspects, so cannot be considered as strongly influencing differences in slope stability. It is concluded that north facing slopes show greatest resistance to erosion. The dense vegetation cover protecting north and west slopes from excessive erosion compared with the relatively sparse cover on south and east facing slopes, compliments the other factors which tend to make north and west facing slopes more stable. The possibility of excessive erosion is therefore greater on south and east facing slopes. Tests using the rainfall simulator reveal soil loss is mostly the result of splash. These tests confirm the stability of the soils in this area. Stability probably results from the overall high aggregation. The greatest soil losses are from soils sampled on south facing slopes. The results of laboratory simulation therefore support the evidence already put forward which suggests that soils on south facing slopes are more susceptable to erosion than soils from north facing slopes.

The process of mass-wasting acting mainly through soil creep is more probable on north and west facing slopes. North and west slopes are conducive to soil creep as a result of the low soil strength and high soil moisture values recorded on these slopes.

Before making any conclusions concerning slope morphology in the

study area it is necessary to decide if erosion without basal corrasion produces steeper or lower slope angle declivities. Schumm (1956) suggested that parallel retreat of slopes may occur, after a regionally characteristic 'pose' has been attained, as long as continued basal stream downcutting or debris removal takes place. Young (1960) suggested parallel retreat was particularly applicable to upper slope elements, especially where structure was important. On the basis of the sources referred to in this study, parallel retreat of slopes has not been observed in areas which lack structural control and active basal removal.

Another concept of slope development which may be applicable to the results obtained in this study is that of time independent slopes (Hack 1960). The concept states that overall lowering of the slope may take place, but that the points of the slope never change in relation to each other. The theory is similar to that of slope as an open system remaining unchanged with time (Strahler, 1950). This theory is only applicable when inflow and outflow of materials occur. In this study the open system theory cannot be adopted because the product of erosion is not carried out of the system. The theories of Hack and Strahler appear to apply only when there is a good correlation between slopes, stream gradient, and lithology.

Strahler (1950) found that slopes protected from recent basal removal of material have significantly lower angles than those where active removal is present. Since in this study there is a similar situation to the protected one described by Strahler, erosion unaccompanied by basal removal is expected to produce lower slope angles. Field evidence for such an assumption has been put forward by a number of researchers. Emery (1947) working in California, concluded:

> Thus it is probable that the small amount of vegetation on south facing slopes of east-west trending valleys must result in a higher rate of erosion through sheet wash, eventually causing the development of gentler slopes where exposure to the sun is greatest.

Melton (1957) working in Arizona found that valley sides having high runoff eroded rapidly and had relatively low slope inclinations. In

the Central Appalachians, Hack and Goodlett (1960) also came to the conclusion that on slopes where runoff is high slope inclination is low. Thornbury (1954), and Packer (1964) stated that the slope exhibiting greatest weathering, sheetwash and mass-wasting would be less steep than slopes which were less susceptable to erosion precesses. The problem of slope development was approached by the use of computer models by Young (1963). He concluded that on slopes where removal of material is mainly by means of creep and wash, a concavo-convex form and slope decline with result.

Wilson (1968 p. 30-31) stated:

> Most observers have claimed that average slope inclination is less on slopes which are being actively eroded than on slopes being less actively eroded.

Savigear (1960) and Schumm (1956) put forward an alternative point of view. They suggested that slope angles are steepened or maintained by corrasion in gullies or runnels. Thus parallel retreat or slope steepening can occur if the runoff is channeled into rills and gullies.

It must be concluded on the basis of both computer models and field observation in various parts of the world, that the removal of upper slope material and subsequent deposition at the base of the slope in the absence of gullying and rilling, results in a decline in mean slope angle, although some local steepening of the upper profile may occur.

Most of the emphasis in this study has been on the zone of maximum declivity, but the analysis of the total slope (4.2.1.) shows a similar slope response to aspect as is obtained using the zone of maximum declivity. The overall tendency in the study area, with an absence of gullying or runnels will be a decline in the relief i.e. net slope lowering with a resultant decrease in slope steepness as basal accumulation occurs.

Analysis shows that slope aspects demonstrating maximum potential

erodibility, south and east slopes, are coincident with the slope aspects which demonstrate significantly higher mean slope angle values. The observed asymmetry of slopes appears contrary to widely accepted theory concerning the development of slopes in the mid-latitudes of the northern hemisphere, i.e. north facing slopes are steeper (Walker 1948, Emery 1947). Some researchers have testified that south facing slopes are sometimes steeper (Smith 1949, Büdel 1953; French 1971; Kennedy 1972). It is significant that all these authors worked in periglacial or sub-Arctic environments. The steeper south facing slopes are explained by basal corrasion of the south facing slope as a result of the debris from solifluction and soil creep on the wetter north facing slope deflecting the stream channel. In mid-latitude areas the reverse is the case, north facing slopes are found to be steeper as slope processes are more active on the south facing slope (Emery 1947).

In this area of hummocky moraine, slope asymmetry appears not to be in tune with contemporary slope processes. In the absence of basal corrasion, slopes experiencing most erosion should exhibit lower mean slope angles. Present slope processes, as measured in the field, do not satisfactorily account for the existing slope form. Microclimate, and its effects on soil erodibility in this area, has not been an effective parameter explaining differences in slope profile response. It must be concluded that the observed asymmetry of slopes is explained by the possibility that these features are relict, which according to King (1957) is not uncommon in temperate latitudes as a result of previous periglacial conditions.

Discussion of Possible Explanations why Slopes have not adjusted to the Contemporary Erosional Processes.

At least three possible explanations can be discussed.

1. Preferred loess distribution in the immediate postglacial period.
2. Ice stress or a minor readvance in the depositional stage.
3. The moraine adopted its asymmetric form during the melting-

out phase when the mound material was in a fluid state.

The first possibility, that the more gentle north and west slopes might be explained by preferred loess distribution, is rejected on the basis of grain size analysis. Samples taken from the surface contain low percentages of silt sized material, and there is no distinct difference in silt content on different aspects, either with surface samples, or samples taken at depth. Loess in this area is therefore not preferentially distributed on any aspect.

Ice push through ice stresses, or a minor ice readvance, as an explanation of the mound morphology is doubtful as evidence of ice stagnation is abundant. Short ridges and dead ice plateau are characteristic of this area, and as Stalker (1960) affirmed, they all typically form when ice movement has practically ceased. Stalker further testified that some knobs investigated in the Big Valley area to the north of Rumsey, were capped with horizontal bedded sediments laid down in water as the ice melted. The undisturbed nature of the sediments suggested the ice could not have been active.

A hypothesis might be that during the melting phase, slope processes no longer in evidence today were active on these slopes. The moraine would have been in a much more fluid state, making the material on the slopes highly susceptible to mass-movement. French (1971) working on Banks Island, N.W.T., in Canada, found the steepest slopes were orientated southwest. He held the predominance of the solifluction process on north and east slopes largely responsible for the observed slope asymmetry. The explanation he offered for the lack of activity of this process on southwest aspects was that these slopes were much drier as a result of westerly winds promoting evaporation on these slopes in the summer period. It is possible that the slope forms in the field area can be attributed to similar causal factors.

Rudberg (1958) proposed that the orientation of stones within moraine might indicate that mass-wasting had taken place. Lundqvist

(1949), has shown that pebbles in an earth flow tend to orientate themselves with the long axis parallel to the direction of flow. In an attempt to identify possible evidence of mass-wasting, microfabric analysis is carried out on two samples taken at depth. Neither sample revealed any significant mineral orientation, nor do tests of liquid limits of slope material at depth, which might have indicated which slopes were relatively more susceptible to flowage, show significant differences between aspects.

The lack of field evidence of soil creep on slopes less exposed to direct insolation does not negate the possibility that mass-wasting of this type may still be active on these slopes. Active soil creep does occur on slopes in the Red Deer River Valley, south of the field area. If the slopes of this area are a response to the action of slow mass-wasting, future emphasis should be placed on the collection of evidence to resolve this problem. Such evidence, however, is not readily apparent in the field area.

Runoff is more probable on slopes exposed to maximum direct insolation, but does not appear to be re-shaping the basic asymmetric form of the mounds in this area. Over a period of 10-11,000 years since deglaciation, runoff has failed to substantially modify south and east facing slopes. This is indicative of the slowness of this process in this area.

The basic asymmetrical form of the mounds probably reflects the action of processes operating in the immediate post-glacial environment. The form of the mounds may, therefore, have been inherited, and modification by contemporary slope processes may not have been substantial. If soil creep is active today, then the slopes of this area may be in equilibrium with present erosional processes. In future work emphasis should be placed on microfabric analysis, as it would seem, on the basis of French's observations (1971), that mass flowage may be the most plausible explanation of the slope morphology in this area.

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APPENDICES

APPENDIX A

INFILTRATION RATES - NORTH SLOPES (cm per hr.)

| Time | Mound Number 1 | 3 | 5 | 6 | 9 | 10 | 11 | 13 | 16 | 19 | Mean* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1min. | 25.80 | 36.30 | 22.92 | 57.32 | 38.21 | 26.75 | 28.66 | 28.66 | 28.66 | 22.93 | 37.72 |
| 5min. | 13.85 | 29.38 | 14.80 | 27.70 | 20.54 | 15.28 | 19.10 | 9.55 | 27.38 | 10.98 | 19.30 |
| 10min. | 10.70 | 18.72 | 9.55 | 20.25 | 16.05 | 13.75 | 11.46 | 6.50 | 13.75 | 10.32 | 13.50 |
| 15min. | 10.31 | 14.33 | 9.92 | 19.10 | 12.61 | 19.87 | 12.61 | 8.79 | 10.56 | 8.78 | 12.99 |
| 20min. | 12.00 | 12.61 | 12.09 | 18.72 | 10.31 | 10.31 | 15.66 | 8.40 | 12.10 | 8.40 | 12.05 |
| 25min. | 11.20 | 12.00 | 9.92 | 14.90 | 11.46 | 11.84 | 14.90 | 8.40 | 12.30 | 8.02 | 11.67 |
| 30min. | 10.72 | 11.10 | 10.70 | 14.90 | 10.70 | 12.22 | 12.61 | 8.02 | 10.50 | 8.78 | 11.06 |
| 45min. | 10.05 | 11.40 | 9.04 | 14.14 | 11.01 | 10.31 | 10.70 | 8.28 | 10.70 | 7.13 | 10.41 |
| 60min. | 10.31 | 12.08 | 7.90 | 14.58 | 10.19 | 10.06 | 10.82 | 9.04 | 11.22 | 7.84 | 10.68 |
| 75min. | 10.05 | 11.16 | 8.40 | 14.00 | 10.82 | 10.31 | 10.82 | 8.85 | 11.10 | 6.11 | 10.36 |
| 90min. | 10.20 | 12.20 | 7.90 | 13.70 | 11.46 | 10.19 | 10.82 | 7.51 | 10.70 | 7.51 | 10.47 |
| 105min. | 10.54 | 11.20 | 8.88 | 13.44 | 10.57 | 10.06 | 10.63 | 8.15 | 11.10 | 6.49 | 10.24 |
| 120min. | 10.32 | 11.40 | 8.40 | 13.50 | 10.70 | 10.19 | 10.82 | 8.28 | 11.10 | 8.40 | 10.52 |
| Mean Infiltration after 15 mins. | 10.31 | 11.56 | 8.89 | 14.67 | 11.00 | 11.65 | 11.22 | 8.36 | 10.87 | 7.63 | |

INFILTRATION RATES - SOUTH SLOPES (cm per hr.)

| Time | Mound Number 1 | 3 | 5 | 6 | 9 | 10 | 13 | 16 | 19 | Mean* |
|---|---|---|---|---|---|---|---|---|---|---|
| 1min. | 15.28 | 32.48 | 51.59 | 22.92 | 19.10 | 19.10 | 28.66 | 24.72 | 28.66 | 24.11 |
| 5min. | 10.98 | 19.50 | 30.09 | 12.42 | 14.33 | 11.46 | 7.64 | 14.81 | 13.38 | 13.06 |
| 10min. | 4.39 | 13.00 | 29.23 | 10.70 | 11.46 | 6.87 | 7.64 | 9.70 | 8.03 | 8.97 |
| 15min. | 4.39 | 8.86 | 24.84 | 7.64 | 9.93 | 6.49 | 5.73 | 7.30 | 9.17 | 7.44 |
| 20min. | 5.40 | 9.90 | 27.70 | 9.17 | 9.93 | 7.64 | 6.11 | 8.20 | 7.83 | 8.02 |
| 25min. | 6.00 | 10.10 | 23.50 | 10.70 | 7.64 | 8.40 | 6.87 | 8.40 | 8.41 | 8.31 |
| 30min. | 5.30 | 11.30 | 23.50 | 12.42 | 7.64 | 7.26 | 6.49 | 6.50 | 9.17 | 8.26 |
| 45min. | 4.30 | 9.00 | 22.42 | 8.40 | 8.02 | 4.84 | 5.60 | 6.00 | 8.28 | 6.80 |
| 60min. | 5.00 | 8.50 | 22.92 | 8.53 | 7.26 | 7.13 | 7.26 | 7.08 | 9.30 | 7.51 |
| 75min. | 4.80 | 8.86 | 19.42 | 8.02 | 6.36 | 8.15 | 5.60 | 7.20 | 9.17 | 7.27 |
| 90min. | 4.80 | 8.20 | 17.20 | 8.80 | 6.62 | 7.00 | 6.11 | 6.30 | 8.66 | 7.06 |
| 105min. | 5.70 | 8.00 | 17.00 | 8.40 | 5.22 | 8.15 | 5.98 | 7.22 | 8.15 | 7.10 |
| 120min. | 4.90 | 8.50 | 17.90 | 8.50 | 5.98 | 7.38 | 4.07 | 7.10 | 8.00 | 6.80 |
| Mean Infiltration after 15 mins. | 4.89 | 8.90 | 20.65 | 8.83 | 7.12 | 7.00 | 5.85 | 6.83 | 8.73 | |

*Excluding Mound 5.

INFILTRATION RATES - EAST SLOPES (cm per hr.)

| Time | Mound Number 1 | 2 | 5 | 6 | 9 | 10 | 11 | 13 | 19 | Mean* |
|---|---|---|---|---|---|---|---|---|---|---|
| 1min. | 24.84 | 32.48 | 72.61 | 26.75 | 21.01 | 21.01 | 21.01 | 43.94 | 33.42 | 28.05 |
| 5min. | 21.01 | 27.91 | 26.31 | 14.33 | 10.50 | 7.16 | 16.71 | 28.66 | 23.88 | 18.77 |
| 10min. | 15.86 | 18.72 | 25.80 | 11.46 | 8.02 | 7.26 | 10.70 | 13.37 | 14.52 | 12.49 |
| 15min. | 10.89 | 14.75 | 24.60 | 12.61 | 5.73 | 3.43 | 12.61 | 12.61 | 11.08 | 11.71 |
| 20min. | 11.50 | 12.20 | 19.20 | 10.31 | 6.49 | 4.58 | 11.46 | 14.14 | 12.22 | 10.36 |
| 25min. | 11.07 | 12.06 | 19.40 | 8.02 | 5.35 | 4.20 | 12.61 | 14.52 | 9.31 | 9.64 |
| 30min. | 8.50 | 12.00 | 18.20 | 6.49 | 4.96 | 4.20 | 12.22 | 14.52 | 14.00 | 9.63 |
| 45min. | 6.90 | 11.40 | 14.00 | 8.91 | 5.09 | 3.05 | 11.91 | 9.80 | 10.20 | 8.40 |
| 60min. | 7.32 | 10.14 | 11.70 | 7.38 | 5.35 | 3.69 | 11.46 | 6.75 | 9.93 | 7.75 |
| 75min. | 5.40 | 10.00 | 11.03 | 9.17 | 5.22 | 2.80 | 10.57 | 8.53 | 9.49 | 7.64 |
| 90min. | 6.54 | 11.30 | 11.90 | 7.89 | 5.47 | 3.31 | 11.71 | 6.87 | 9.12 | 7.77 |
| 105min. | 7.23 | 10.26 | 10.95 | 8.10 | 5.60 | 3.18 | 12.10 | 9.55 | 7.01 | 7.88 |
| 120min. | 7.10 | 8.10 | 10.80 | 7.40 | 5.09 | 3.18 | 11.46 | 6.11 | 9.04 | 7.18 |
| Mean Infiltration after 15 mins. | 7.48 | 10.99 | 15.27 | 8.49 | 5.31 | 3.35 | 11.75 | 9.34 | 9.99 | |

INFILTRATION RATES - WEST SLOPES (cm per hr.)

| Time | Mound Number 6 | 10 | 11 | 13 | 16 | 19 | Mean |
|---|---|---|---|---|---|---|---|
| 1min. | 38.21 | 49.68 | 19.10 | 19.10 | 34.52 | 30.21 | 31.80 |
| 5min. | 29.61 | 26.75 | 9.55 | 9.07 | 20.76 | 17.89 | 18.93 |
| 10min. | 22.92 | 21.40 | 8.78 | 5.73 | 16.72 | 10.72 | 14.37 |
| 15min. | 18.72 | 17.57 | 9.93 | 8.02 | 15.08 | 14.26 | 13.93 |
| 20min. | 18.91 | 19.10 | 7.05 | 7.64 | 14.27 | 12.53 | 13.25 |
| 25min. | 17.38 | 17.19 | 9.55 | 7.64 | 12.89 | 9.87 | 12.43 |
| 30min. | 16.62 | 17.57 | 8.78 | 8.02 | 12.70 | 11.94 | 12.60 |
| 45min. | 15.79 | 10.82 | 10.19 | 7.13 | 10.98 | 11.24 | 11.02 |
| 60min. | 12.61 | 10.70 | 8.53 | 8.66 | 10.70 | 10.65 | 10.31 |
| 75min. | 11.71 | 10.82 | 8.28 | 7.77 | 9.64 | 9.02 | 9.54 |
| 90min. | 11.65 | 9.55 | 8.78 | 5.98 | 9.36 | 9.52 | 9.12 |
| 105min. | 12.06 | 10.82 | 8.15 | 6.87 | 9.51 | 8.67 | 9.34 |
| 120min. | 11.92 | 10.70 | 8.28 | 7.26 | 9.48 | 9.05 | 9.44 |
| Mean Infiltration after 15 mins. | 13.88 | 12.31 | 8.86 | 7.46 | 10.93 | 10.54 | |

*Excluding Mound 5.

APPENDIX B

AGGREGATION (as percentage of sample weight)

| Mound No. | Aspect | Dry 3 mm | Dry 2 mm | Dry 1 mm | Dry 0.5 mm | Wet 3 mm | Wet 2 mm | Wet 1 mm | Wet 0.5 mm |
|---|---|---|---|---|---|---|---|---|---|
| 1 | North | 57.723 | 8.094 | 15.400 | 9.505 | 28.022 | 8.123 | 15.056 | 12.726 |
| | South | 28.035 | 4.487 | 11.413 | 16.668 | 22.172 | 5.303 | 9.769 | 13.521 |
| | East | 29.371 | 4.792 | 8.313 | 14.527 | 24.621 | 4.029 | 6.486 | 11.587 |
| 2 | North | 34.142 | 6.024 | 12.653 | 14.202 | 25.439 | 5.894 | 10.740 | 13.673 |
| | South | 21.473 | 5.247 | 9.854 | 15.405 | 18.342 | 5.024 | 8.798 | 11.157 |
| | West | 37.728 | 6.354 | 11.225 | 12.274 | 20.500 | 7.123 | 11.504 | 11.846 |
| 3 | North | 38.537 | 6.345 | 10.981 | 9.654 | 33.149 | 7.431 | 9.105 | 10.728 |
| | South | 18.261 | 3.009 | 8.337 | 12.893 | 13.874 | 3.507 | 7.695 | 11.344 |
| | East | 31.752 | 4.507 | 11.862 | 9.684 | 19.438 | 5.694 | 10.743 | 10.812 |
| 4 | North | 22.849 | 5.421 | 10.653 | 17.315 | 19.349 | 3.926 | 7.451 | 13.848 |
| | South | 19.489 | 4.427 | 7.891 | 13.974 | 12.297 | 4.546 | 6.432 | 12.417 |
| | East | 15.763 | 3.196 | 6.507 | 19.430 | 7.840 | 2.892 | 4.865 | 13.744 |
| | West | 20.749 | 4.960 | 11.427 | 19.095 | 16.543 | 3.820 | 8.064 | 13.716 |
| 5 | North | 36.842 | 5.608 | 11.710 | 14.438 | 30.026 | 4.972 | 9.642 | 13.902 |
| | South | 31.240 | 3.935 | 10.986 | 18.422 | 26.543 | 4.362 | 9.848 | 15.984 |
| | East | 29.417 | 3.002 | 9.836 | 17.650 | 21.586 | 3.838 | 7.922 | 15.955 |
| 6 | North | 36.199 | 5.208 | 12.654 | 17.382 | 25.906 | 5.342 | 10.005 | 15.088 |
| | South | 25.875 | 5.020 | 11.236 | 11.457 | 11.223 | 3.984 | 8.405 | 10.217 |
| | East | 38.294 | 4.448 | 10.122 | 18.360 | 24.602 | 5.806 | 8.768 | 13.386 |
| | West | 40.268 | 4.753 | 9.030 | 11.694 | 34.009 | 4.921 | 9.209 | 11.495 |
| 7 | North | 30.233 | 6.207 | 10.630 | 15.265 | 25.723 | 4.071 | 9.653 | 14.980 |
| | South | 17.590 | 3.837 | 10.774 | 16.688 | 16.671 | 3.910 | 8.405 | 11.096 |
| | East | 11.532 | 3.723 | 10.354 | 24.628 | 9.314 | 4.196 | 9.084 | 14.575 |
| 8 | North | 21.360 | 4.760 | 11.897 | 25.138 | 18.449 | 3.610 | 8.206 | 12.970 |
| | South | 6.712 | 3.729 | 7.064 | 11.301 | 7.115 | 2.925 | 6.795 | 9.686 |
| | East | 27.170 | 4.221 | 8.877 | 11.141 | 22.192 | 5.129 | 9.094 | 11.684 |
| | West | 22.654 | 3.728 | 8.255 | 10.932 | 18.943 | 4.023 | 7.544 | 9.821 |
| 9 | North | 14.688 | 7.239 | 14.367 | 14.474 | 12.066 | 8.146 | 12.321 | 14.328 |
| | South | 9.274 | 7.584 | 13.964 | 14.636 | 8.260 | 6.046 | 12.878 | 14.006 |
| | East | 10.512 | 6.172 | 13.820 | 13.483 | 9.721 | 5.452 | 12.121 | 13.573 |
| 10 | North | 37.120 | 5.267 | 12.274 | 14.305 | 34.404 | 5.583 | 9.745 | 11.576 |
| | South | 26.431 | 4.829 | 10.524 | 13.562 | 19.386 | 5.634 | 9.946 | 12.020 |
| | East | 33.782 | 4.080 | 9.656 | 15.274 | 24.523 | 4.892 | 9.089 | 13.134 |
| | West | 31.621 | 5.724 | 12.342 | 16.891 | 27.489 | 6.143 | 10.008 | 16.342 |

AGGREGATION (as percentage of sample weight)

| Mound No. | Aspect | Dry 3 mm | Dry 2 mm | Dry 1 mm | Dry 0.5 mm | Wet 3 mm | Wet 2 mm | Wet 1 mm | Wet 0.5 mm |
|---|---|---|---|---|---|---|---|---|---|
| 11 | North | 33.865 | 6.172 | 11.510 | 16.496 | 26.843 | 6.374 | 9.523 | 14.409 |
| | East | 44.203 | 6.384 | 12.096 | 11.852 | 34.178 | 7.575 | 11.639 | 12.337 |
| | West | 46.166 | 6.577 | 10.143 | 11.293 | 34.769 | 5.483 | 9.348 | 11.532 |
| 12 | North | 38.823 | 5.868 | 11.856 | 12.005 | 31.718 | 6.025 | 10.847 | 10.596 |
| | South | 25.017 | 6.218 | 10.146 | 10.836 | 19.767 | 7.542 | 10.012 | 8.573 |
| | East | 31.504 | 4.603 | 8.685 | 12.630 | 26.421 | 5.608 | 8.742 | 11.920 |
| | West | 34.189 | 5.769 | 9.490 | 16.773 | 30.988 | 6.178 | 8.625 | 12.853 |
| 13 | North | 29.371 | 5.651 | 10.628 | 17.090 | 15.029 | 5.972 | 7.882 | 13.246 |
| | South | 23.943 | 5.567 | 10.396 | 13.070 | 9.552 | 4.133 | 7.493 | 10.724 |
| | East | 24.784 | 5.582 | 9.295 | 15.968 | 6.655 | 3.006 | 5.598 | 10.337 |
| | West | 30.090 | 4.288 | 9.586 | 15.432 | 14.344 | 4.556 | 7.584 | 12.102 |
| 14 | North | 10.632 | 6.052 | 11.973 | 17.860 | 9.341 | 5.931 | 10.015 | 14.118 |
| | South | 13.191 | 7.426 | 13.603 | 15.415 | 10.152 | 8.899 | 13.543 | 16.612 |
| | East | 13.738 | 5.469 | 11.655 | 15.183 | 10.700 | 10.468 | 6.621 | 14.243 |
| | West | 14.139 | 11.165 | 7.017 | 19.981 | 11.538 | 7.934 | 13.615 | 16.100 |
| 15 | North | 9.869 | 6.147 | 20.886 | 8.403 | 3.799 | 7.483 | 14.002 | 19.710 |
| | East | 3.479 | 3.946 | 11.187 | 23.621 | 0.883 | 3.585 | 9.205 | 16.419 |
| | West | 6.205 | 8.720 | 21.317 | 21.514 | 2.145 | 7.247 | 16.592 | 18.360 |
| 16 | North | 35.265 | 5.591 | 12.274 | 13.420 | 31.319 | 4.799 | 10.161 | 12.296 |
| | South | 15.521 | 3.845 | 10.502 | 13.042 | 14.480 | 3.299 | 7.639 | 12.871 |
| | West | 25.677 | 5.522 | 10.879 | 13.389 | 19.411 | 5.464 | 10.203 | 13.607 |
| 17 | North | 41.590 | 5.528 | 11.987 | 15.815 | 33.532 | 5.864 | 9.748 | 12.475 |
| | South | 14.958 | 4.424 | 8.186 | 17.585 | 9.208 | 4.966 | 8.672 | 13.600 |
| | East | 15.007 | 3.938 | 11.053 | 16.538 | 10.823 | 4.209 | 10.395 | 15.512 |
| | West | 39.889 | 5.286 | 8.456 | 10.461 | 36.180 | 5.222 | 8.536 | 10.628 |
| 18 | North | 47.838 | 5.445 | 9.442 | 13.115 | 34.656 | 6.247 | 10.059 | 11.662 |
| | South | 14.486 | 4.054 | 9.618 | 13.321 | 10.463 | 4.397 | 8.119 | 11.231 |
| | East | 17.276 | 6.245 | 17.263 | 19.530 | 8.914 | 15.334 | 7.255 | 17.276 |
| | West | 33.704 | 7.120 | 9.746 | 15.799 | 25.653 | 7.271 | 9.403 | 14.464 |
| 19 | North | 48.321 | 5.751 | 11.725 | 12.817 | 30.957 | 5.381 | 11.329 | 15.003 |
| | South | 18.666 | 5.174 | 9.707 | 13.964 | 8.454 | 5.150 | 8.532 | 12.810 |
| | East | 33.041 | 6.102 | 11.639 | 13.864 | 16.899 | 4.955 | 9.561 | 12.073 |
| | West | 49.460 | 7.117 | 12.013 | 12.909 | 17.026 | 4.753 | 11.856 | 16.693 |
| 20 | North | 15.315 | 8.424 | 16.303 | 15.991 | 12.196 | 8.938 | 13.317 | 15.039 |
| | South | 15.269 | 4.939 | 11.814 | 14.542 | 10.605 | 4.874 | 7.300 | 12.974 |
| | West | 13.221 | 8.946 | 13.774 | 25.430 | 9.357 | 10.936 | 11.742 | 12.690 |

APPENDIX C

## GRAIN SIZE INDICES
(As Percentages of Sample Weights)

SURFACE HORIZON - NORTH

| Mound No. | 1 mm | 0.5 mm | 0.250 mm | 0.125 mm | 0.063 mm | 0.020 mm | 0.005 mm | 0.002 mm | 0.002 mm |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.30 | 2.30 | 12.00 | 18.50 | 11.70 | 13.20 | 12.00 | 10.00 | 20.00 |
| 3 | 0.40 | 2.30 | 12.60 | 31.60 | 11.60 | 9.50 | 7.00 | 8.00 | 17.00 |
| 5 | 2.96 | 3.07 | 13.23 | 18.12 | 12.54 | 16.08 | 7.00 | 0.00 | 27.00 |
| 6 | 4.99 | 7.55 | 13.92 | 20.53 | 14.17 | 10.84 | 11.00 | 2.00 | 15.00 |
| 9 | 1.70 | 2.38 | 8.88 | 14.92 | 12.37 | 18.45 | 25.95 | 1.79 | 13.42 |
| 10 | 1.24 | 2.19 | 10.59 | 18.85 | 16.42 | 22.48 | 14.10 | 7.46 | 6.63 |
| 11 | 2.20 | 2.88 | 9.69 | 15.00 | 12.30 | 14.34 | 17.43 | 10.38 | 15.00 |
| 13 | 1.20 | 3.70 | 10.50 | 19.90 | 12.90 | 7.75 | 17.00 | 1.00 | 26.00 |
| 16 | 0.70 | 3.70 | 13.50 | 26.50 | 18.10 | 22.45 | 8.00 | 2.00 | 5.00 |
| 19 | 7.20 | 6.40 | 15.60 | 20.20 | 11.30 | 4.27 | 20.00 | 1.00 | 14.00 |

SURFACE HORIZON - SOUTH

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2.20 | 3.70 | 11.48 | 21.34 | 13.72 | 13.58 | 2.00 | 12.00 | 20.00 |
| 3 | 2.20 | 2.70 | 12.30 | 20.10 | 11.50 | 12.13 | 8.00 | 10.00 | 21.00 |
| 5 | 1.75 | 2.79 | 12.22 | 22.28 | 15.55 | 16.41 | 8.00 | 0.00 | 21.00 |
| 6 | 2.49 | 3.02 | 12.50 | 27.33 | 19.94 | 7.72 | 11.00 | 1.00 | 15.00 |
| 9 | 0.89 | 2.52 | 10.42 | 19.53 | 14.40 | 18.17 | 19.85 | 9.45 | 4.72 |
| 10 | 2.49 | 3.68 | 11.93 | 19.77 | 17.69 | 13.99 | 8.68 | 10.41 | 11.28 |
| 13 | 1.39 | 2.46 | 10.09 | 22.59 | 15.04 | 12.48 | 8.53 | 3.87 | 23.27 |
| 16 | 2.00 | 3.80 | 12.70 | 21.10 | 14.90 | 11.45 | 11.00 | 5.00 | 17.00 |
| 19 | 1.90 | 6.00 | 15.10 | 24.80 | 7.10 | 16.04 | 9.00 | 12.00 | 8.00 |

SURFACE HORIZON - EAST

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.80 | 3.80 | 13.20 | 21.20 | 13.70 | 17.00 | 11.00 | 0.00 | 18.00 |
| 3 | 0.10 | 2.70 | 11.70 | 20.00 | 12.60 | 12.91 | 8.00 | 6.00 | 25.00 |
| 5 | 2.57 | 4.08 | 13.55 | 19.86 | 11.48 | 10.39 | 10.00 | 5.00 | 23.00 |
| 6 | 2.20 | 4.50 | 11.90 | 21.90 | 14.80 | 13.64 | 5.00 | 7.00 | 19.00 |
| 9 | 1.63 | 2.61 | 10.94 | 23.27 | 14.42 | 17.30 | 5.81 | 6.53 | 17.43 |
| 10 | 1.70 | 2.44 | 9.74 | 20.05 | 14.84 | 11.74 | 4.26 | 6.39 | 28.79 |
| 11 | 2.66 | 2.64 | 19.37 | 19.37 | 13.81 | 21.88 | 7.01 | 21.83 | 0.00 |
| 13 | 1.41 | 3.32 | 10.40 | 22.12 | 14.89 | 10.83 | 9.46 | 12.04 | 15.48 |
| 19 | 1.60 | 3.80 | 9.90 | 18.50 | 15.10 | 16.10 | 4.00 | 12.00 | 19.00 |

SURFACE HORIZON - WEST

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 6 | 2.20 | 4.09 | 12.82 | 25.21 | 18.50 | 8.18 | 7.00 | 7.00 | 15.00 |
| 10 | 2.02 | 3.18 | 11.45 | 20.16 | 15.16 | 11.54 | 6.25 | 7.29 | 22.92 |
| 11 | 1.93 | 3.30 | 11.52 | 19.22 | 12.91 | 11.37 | 10.59 | 7.06 | 22.06 |
| 13 | 1.26 | 2.94 | 11.18 | 20.83 | 13.20 | 9.23 | 11.67 | 11.67 | 17.96 |
| 16 | 2.10 | 6.90 | 13.80 | 20.50 | 13.10 | 11.52 | 10.00 | 2.00 | 20.00 |
| 19 | 5.90 | 7.80 | 14.00 | 18.40 | 5.90 | 10.91 | 10.00 | 17.00 | 10.00 |

GRAIN SIZE INDICES
(As Percentages of Sample Weights)

DEPTH 30 CM - NORTH

| Mound No. | 1 mm | 0.5 mm | 0.250 mm | 0.125 mm | 0.063 mm | 0.020 mm | 0.005 mm | 0.002 mm | 0.002 mm |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.20 | 3.65 | 10.42 | 19.86 | 12.82 | 14.00 | 4.00 | 11.00 | 23.00 |
| 3 | 1.00 | 1.90 | 14.40 | 33.20 | 10.50 | 11.51 | 4.00 | 4.00 | 18.00 |
| 5 | 1.70 | 3.22 | 12.67 | 20.15 | 9.90 | 13.43 | 9.00 | 6.00 | 24.50 |
| 6 | 2.30 | 6.70 | 15.60 | 17.20 | 7.70 | 7.49 | 7.00 | 6.00 | 30.00 |
| 9 | 2.24 | 2.98 | 10.55 | 16.54 | 9.27 | 20.09 | 6.38 | 2.39 | 29.52 |
| 10 | 0.69 | 2.18 | 8.09 | 12.79 | 8.91 | 12.99 | 12.71 | 8.47 | 33.19 |
| 11 | 0.92 | 3.09 | 11.31 | 16.36 | 11.51 | 18.11 | 12.39 | 10.97 | 14.76 |
| 13 | 1.13 | 2.65 | 9.59 | 13.84 | 12.12 | 16.66 | 9.00 | 7.00 | 28.00 |
| 16 | 4.00 | 4.20 | 15.00 | 21.70 | 12.70 | 11.40 | 11.00 | 7.00 | 13.00 |
| 19 | 1.80 | 3.30 | 13.30 | 18.90 | 11.30 | 5.35 | 12.00 | 3.00 | 31.00 |

DEPTH 30 CM - SOUTH

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.70 | 2.45 | 10.00 | 14.82 | 11.49 | 14.44 | 14.00 | 5.00 | 26.00 |
| 3 | 0.70 | 2.40 | 10.60 | 19.60 | 13.00 | 15.65 | 6.00 | 9.00 | 23.00 |
| 5 | 1.52 | 3.44 | 10.11 | 16.23 | 12.13 | 12.55 | 10.41 | 8.10 | 25.00 |
| 6 | 2.10 | 3.80 | 11.90 | 16.40 | 9.70 | 10.03 | 11.00 | 4.00 | 31.00 |
| 9 | 1.50 | 2.73 | 10.88 | 19.26 | 12.82 | 14.74 | 7.79 | 17.92 | 12.47 |
| 10 | 1.74 | 2.84 | 11.51 | 22.71 | 22.27 | 11.32 | 7.52 | 5.01 | 15.54 |
| 13 | 1.88 | 2.73 | 10.47 | 19.06 | 12.79 | 11.18 | 10.46 | 1.90 | 29.50 |
| 16 | 0.30 | 0.80 | 2.20 | 4.90 | 8.90 | 17.86 | 19.00 | 9.00 | 37.00 |
| 19 | 1.80 | 3.10 | 11.60 | 16.90 | 10.90 | 11.68 | 9.00 | 5.00 | 30.00 |

DEPTH 30 CM - EAST

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.22 | 2.07 | 9.31 | 17.59 | 11.26 | 10.55 | 14.00 | 7.00 | 27.00 |
| 3 | 2.50 | 2.40 | 9.90 | 16.20 | 10.80 | 16.17 | 8.00 | 8.00 | 26.00 |
| 5 | 1.40 | 3.26 | 12.02 | 16.78 | 12.25 | 14.03 | 8.00 | 9.00 | 23.00 |
| 6 | 2.00 | 3.20 | 11.90 | 22.20 | 12.90 | 11.80 | 3.00 | 12.00 | 22.00 |
| 9 | 0.78 | 2.19 | 9.45 | 18.45 | 10.79 | 24.07 | 4.64 | 10.06 | 20.13 |
| 10 | 2.15 | 3.18 | 14.24 | 19.20 | 13.61 | 7.18 | 7.11 | 14.22 | 17.26 |
| 11 | 1.39 | 2.62 | 10.65 | 18.00 | 12.76 | 15.59 | 14.17 | 6.20 | 18.60 |
| 13 | 1.09 | 2.56 | 10.81 | 18.83 | 12.23 | 14.55 | 7.40 | 7.40 | 25.00 |
| 19 | 1.50 | 3.00 | 11.60 | 18.20 | 10.90 | 9.79 | 8.00 | 7.00 | 30.00 |

DEPTH 30 CM - WEST

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 6 | 1.60 | 3.10 | 11.40 | 16.50 | 11.00 | 11.19 | 11.00 | 7.00 | 27.00 |
| 10 | 0.98 | 3.18 | 11.28 | 16.31 | 14.60 | 14.45 | 9.97 | 7.12 | 22.07 |
| 11 | 1.95 | 3.85 | 14.74 | 19.87 | 9.44 | 3.06 | 14.87 | 9.39 | 23.48 |
| 13 | 0.83 | 2.33 | 11.79 | 20.91 | 12.74 | 11.42 | 9.79 | 8.28 | 21.85 |
| 16 | 1.60 | 5.30 | 14.00 | 18.10 | 11.00 | 7.92 | 3.00 | 1.00 | 38.00 |
| 19 | 2.50 | 3.30 | 10.90 | 14.80 | 8.90 | 7.59 | 0.00 | 24.00 | 28.00 |

GRAIN SIZE INDICES
(As Percentages of Sample Weights)

BELOW (Ca) LAYER - NORTH

| Mound No. | 1 mm | 0.5 mm | 0.250 mm | 0.125 mm | 0.063 mm | 0.020 mm | 0.005 mm | 0.002 mm | 0.002 mm |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.60 | 2.11 | 9.32 | 15.44 | 11.60 | 13.93 | 13.00 | 5.00 | 27.00 |
| 3 | 1.70 | 2.50 | 9.70 | 17.00 | 11.90 | 16.18 | 6.00 | 8.00 | 27.00 |
| 5 | 3.26 | 5.52 | 14.52 | 17.82 | 12.72 | 13.16 | 6.00 | 4.00 | 23.00 |
| 6 | 1.70 | 3.60 | 11.90 | 14.80 | 9.70 | 14.22 | 11.00 | 0.00 | 33.00 |
| 9 | 1.80 | 2.39 | 8.96 | 15.20 | 10.77 | 9.01 | 13.19 | 15.08 | 23.56 |
| 10 | 0.41 | 2.21 | 10.88 | 18.72 | 12.49 | 8.02 | 9.16 | 7.75 | 30.30 |
| 11 | 1.69 | 2.22 | 9.16 | 14.35 | 11.28 | 21.31 | 14.98 | 4.99 | 19.97 |
| 13 | 0.50 | 2.10 | 11.70 | 19.20 | 12.20 | 9.30 | 10.00 | 0.00 | 35.00 |
| 16 | 3.63 | 2.37 | 12.71 | 18.96 | 11.75 | 13.58 | 11.00 | 1.00 | 25.00 |
| 19 | 1.13 | 2.65 | 9.59 | 13.84 | 12.12 | 16.66 | 9.00 | 7.00 | 28.00 |

BELOW (Ca) LAYER - SOUTH

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.80 | 3.00 | 10.60 | 16.50 | 12.30 | 17.74 | 8.00 | 4.00 | 26.00 |
| 3 | 1.56 | 3.13 | 10.61 | 13.73 | 13.47 | 12.52 | 9.00 | 8.00 | 28.00 |
| 5 | 1.91 | 2.30 | 10.50 | 18.78 | 14.30 | 12.20 | 7.00 | 6.00 | 27.00 |
| 6 | 1.70 | 3.00 | 10.10 | 14.50 | 10.90 | 4.00 | 22.00 | 2.00 | 31.00 |
| 9 | 2.35 | 2.63 | 10.83 | 19.35 | 13.07 | 6.36 | 11.68 | 13.74 | 19.92 |
| 10 | 0.99 | 1.66 | 9.47 | 14.82 | 11.84 | 15.60 | 10.67 | 8.53 | 26.32 |
| 13 | 1.37 | 2.30 | 9.20 | 17.97 | 11.94 | 13.43 | 11.86 | 8.89 | 22.99 |
| 16 | 0.50 | 0.70 | 2.30 | 3.80 | 6.20 | 22.44 | 19.00 | 12.00 | 33.00 |
| 19 | 2.40 | 3.20 | 10.74 | 15.29 | 12.54 | 8.00 | 8.00 | 8.00 | 25.00 |

BELOW (Ca) LAYER - EAST

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.01 | 2.27 | 9.51 | 14.67 | 11.39 | 9.69 | 15.17 | 8.43 | 27.82 |
| 3 | 1.30 | 2.50 | 10.20 | 16.50 | 12.00 | 11.50 | 9.00 | 8.00 | 29.00 |
| 5 | 1.53 | 3.83 | 9.69 | 17.96 | 14.26 | 10.73 | 9.00 | 7.00 | 26.00 |
| 6 | 1.20 | 2.70 | 10.20 | 16.00 | 11.30 | 18.58 | 6.00 | 4.00 | 30.00 |
| 9 | 0.93 | 2.15 | 9.06 | 18.39 | 13.45 | 18.47 | 7.63 | 3.47 | 26.38 |
| 10 | 2.12 | 3.16 | 9.25 | 12.44 | 12.01 | 15.88 | 9.59 | 12.47 | 23.03 |
| 11 | 2.46 | 2.23 | 8.78 | 14.75 | 11.08 | 16.64 | 12.57 | 12.57 | 18.86 |
| 13 | 1.11 | 2.58 | 10.39 | 17.19 | 11.59 | 11.87 | 11.94 | 10.24 | 23.04 |
| 19 | 6.20 | 5.20 | 11.00 | 16.60 | 10.80 | 11.15 | 9.00 | 4.00 | 26.00 |

BELOW (Ca) LAYER - WEST

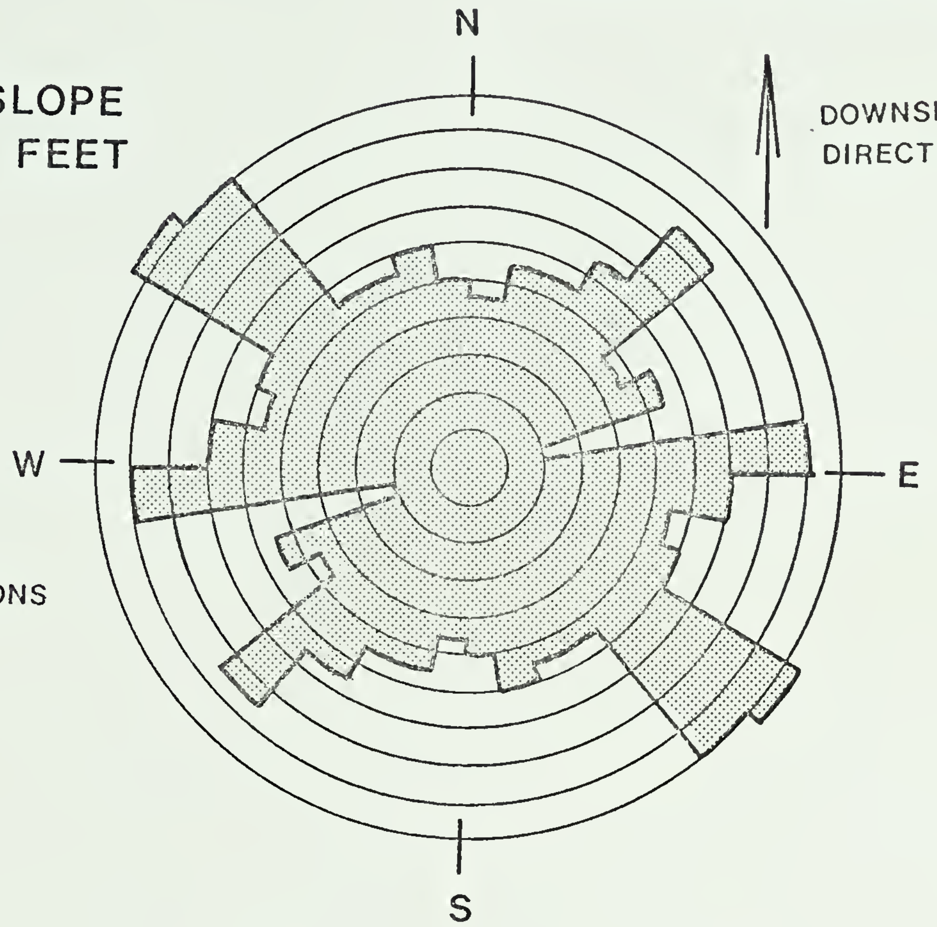
| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 6 | 1.90 | 2.50 | 9.50 | 15.50 | 11.30 | 22.29 | 4.00 | 8.00 | 25.00 |
| 10 | 1.45 | 4.29 | 13.19 | 23.10 | 18.01 | 15.01 | 0.00 | 0.00 | 24.90 |
| 11 | 0.75 | 2.45 | 10.49 | 16.00 | 11.94 | 15.01 | 8.36 | 9.88 | 25.08 |
| 13 | 0.74 | 1.91 | 8.75 | 19.34 | 13.31 | 20.28 | 7.28 | 4.85 | 23.48 |
| 16 | 2.00 | 3.20 | 10.80 | 16.70 | 11.50 | 12.80 | 14.00 | 4.00 | 25.00 |
| 19 | 2.70 | 2.90 | 10.90 | 14.90 | 11.50 | 11.08 | 9.00 | 9.00 | 28.00 |

APPENDIX D

# MICROFABRIC DIAGRAMS

CIRCLES AT 2 OBSERVATION FREQUENCY

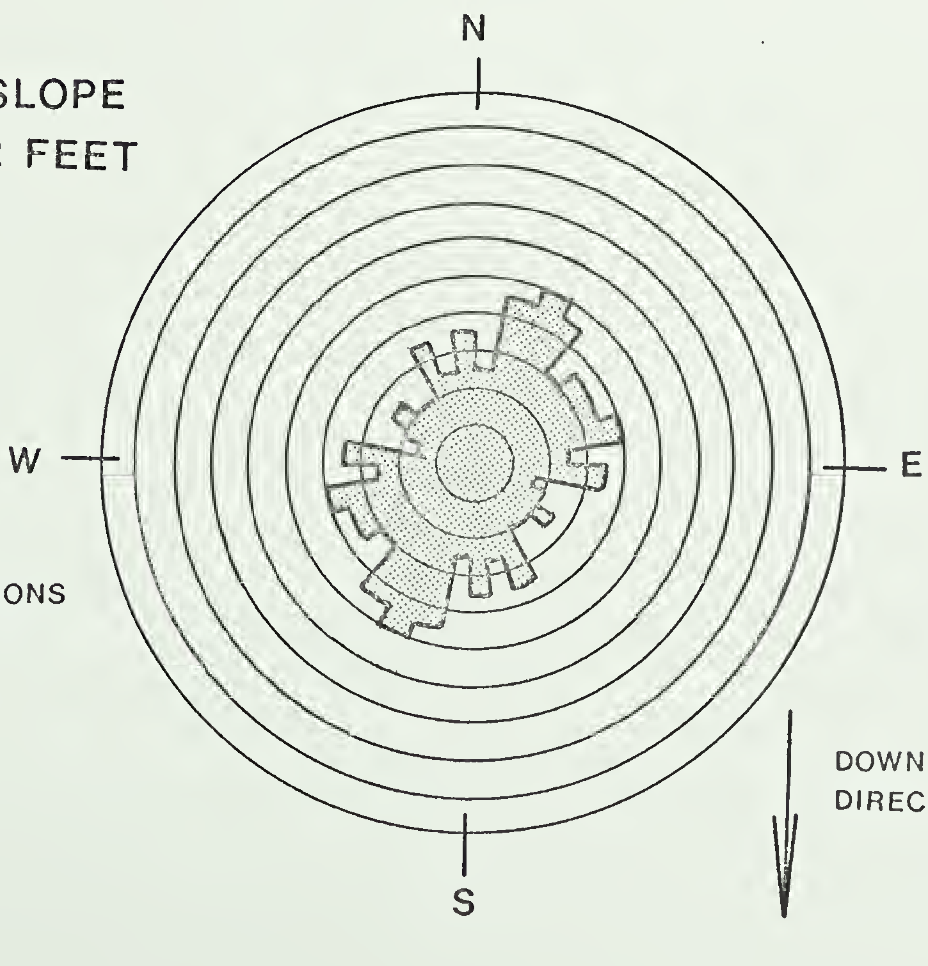
NORTH SLOPE
DEPTH 3 FEET




DOWNSLOPE DIRECTION

225 OBSERVATIONS

SOUTH SLOPE
DEPTH 2 FEET




112 OBSERVATIONS

DOWNSLOPE DIRECTION